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THE DESIGN
OF
RAILWAY LOCATION

A STUDY OF THE PHYSICAL AND ECONOMIC CONDITIONS THAT CONTROL THE LOCATION OF RAILWAYS IN ORDER THAT THEIR OPERATION MAY BE AT MAXIMUM SAFETY AND EFFICIENCY

BY
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PREFACE

MANY radical changes in railway operation have occurred within recent years which render a study of the Design of Railway Location a matter of vital importance in railway engineering at the present time. Owing to these changes in traffic and operating conditions, many of the railways of the country are being revised and relocated, and extensive regrouping and rearrangements of systems have been made and others will probably be made in the future. These facts call for a careful study of the principles that affect the location of a railroad, and, at the same time, the more complete data related to operation now available permit a more exact and scientific study of this subject than has been possible previously. This volume was prepared with a view chiefly to the work that is being done in this connection, although considerable attention is devoted to the projection of new location.

The book is intended for use as a text in classes in technical schools rather than as a treatise on the subject, although it is hoped that the material included may be of value to those engineers engaged in practical railroad work. It has grown out of notes prepared for the author's classes in railway location and, in some respects, presents an outline rather than an exhaustive treatment.

The basic idea in the preparation of the book has been to explain and develop underlying principles rather than to describe current practice. This point of view has been taken in order to enhance the value of the book as a text, and also because other books have been written describing in detail the practical procedure in railway location. The fundamental conception of the subject is that railway location is essentially a problem of rational design to be based on certain physical and economic principles, and the author has endeavored to explain how, with given traffic and operating conditions, the transportation plant might be designed that would handle the traffic most safely and economically. Considerable space is devoted to the elementary principles of railway economics in order that the student may comprehend the relation of fixed charges to location, for economy of transportation depends as much upon fixed charges as upon operating expenses.

An attempt has been made to give credit in the body of the text and in foot-notes to the sources of subject matter taken from other writings, but special mention should be made of the monumental work by Mr. A. M. Wellington, "The Economic Theory of Railway Location," which had such a marked influence on railroad building during the latter part of the last century, and of the Proceedings of the American Railway Engineering Association for a large amount of information contributed and collected by its committees. Statistical data have been abstracted in some places from the reports of the Interstate Commerce Commission without specific reference. The object has been to make this material available for convenient use. The chief difficulty has been to condense the material at hand into the compass of a reasonably sized volume, and in order to do so much that was originally included has been omitted and other matter has been rigorously compressed. The relative importance of the topics treated has been kept in mind and an effort made to proportion the discussions accordingly.

C. C. W.

University of Kansas, Lawrence, Kansas,
January 1, 1917.

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DESIGN OF RAILWAY LOCATION

CHAPTER I

INTRODUCTION

HISTORICAL REVIEW OF RAILWAY DEVELOPMENT

Introduction. No other industry in the United States has contributed so much toward the development of the country as have the railroads. No other feature of its civilization is so intimately connected and intertwined with its material progress as are the railroads. Until these highways of traffic were built, the United States was chiefly a small group of struggling commonwealths along the Atlantic Seaboard with a few settlements scattered along the natural waterways of the country, constituting in all scarcely a suggestion of that immensity of national as well as commercial growth that has become such a characteristic feature of the nation's history. This growth was simultaneous with the building of railroads, the two being closely connected and mutually interdependent.

With the exception of agriculture, no other industry in the United States at the present time, from the viewpoint either of the number of men employed or of the amount of capital invested, is so important as the railroads; nearly two million persons being employed directly and immense armies of men employed indirectly, and the huge sum of about fifteen billion dollars representing their net capitalization.

Naturally many of the problems of railroad building and service are those of the engineer, and among these, that of the location of the line as governed by economic and physical conditions is the first and by no means the least. A railroad is located by fixing its alignment and determining its gradients, each of which processes is a complicated problem requiring a careful study of economical and physical conditions and an intimate knowledge of railway operation for its solution. Safety and economy of operation are the criteria of successful accomplishment. The intricacies of railway financing, organization, legislation and legal status of carriers, valuation and rate making have a very direct bearing on many of the larger questions affecting location and should be understood by the locating engineer. The first question to be answered is whether to build or not to build, and this should be determined only after a careful study of the conditions as affected to a great extent by the factors above mentioned.

Probably the best approach to a study of The Design of Railway Location is an acquaintance with railroad growth of the past. Indeed, a thoroughgoing study of the history of railway development would be altogether profitable, but space will admit of only a very brief historical review of the subject in which an effort will be made, not only to relate the facts, but, so far as practicable, to point out those features which have had a marked influence on the railway situation of the present time.

Early Railroads. The first railroad of which there is any record seems to have been a crude affair devised to facilitate the hauling of coal at the mines near Newcastle-on-Tyne in England, about the middle of the seventeenth century, as Robert Stevenson states that it was in use there before 1671. This road was scarcely a suggestion of the modern railroad, the rails consisting of timbers laid straight and the cars being drawn by horses. The scarcity of timber, however, led to the introduction in 1767 of flat cast-iron rails, and in 1789 " edge rails " were first employed, which necessitated putting the flanges on the wheels. In 1800 Benjamin Ostram made the improvement of supporting the rails on stone instead of timbers, and his type of construction became known as " Ostram roads " or later as " Tram roads," from which was derived the modern tramway. Malleable-iron rails were introduced in 1808. The gauge adopted from the first was 4 ft. $8\frac{1}{2}$ ins. inside to inside, as that was the prevailing width of the carriages at that time, which at first were owned by the public, who paid toll for the use of the rails. The first chartered railway, however, was built in England from Wandsworth to Croydon, in the suburbs of London, in the year 1801. Thus in the very dawn of the century was begun that industry which, during that century, was to play so important a part in bringing about the most marvelous material and industrial achievement in recorded human history.

Early Locomotives. Although wagons carrying steam engines which would travel on ordinary roads by means of their own power had been built by Oliver Evans of Philadelphia in 1801 and by Robert Trevithick, a Cornish engineer, in 1804, the first locomotive constructed to run on rails was built by William Hedley and Timothy Hackworth in 1813. This consisted of a boiler and two vertical cylinders and was dubbed "Puffing Billy." George Stephenson, who is commonly considered as the originator of the locomotive, finished a similar contrivance the next year and continued to improve his invention until it actually became a commercial success. In 1822 he had several in use at the Hatton Colliery, where he was chief engineer, and had converted the tramway into a steam road. The opening of this tramway as a steam railroad on November 18, 1822, was attended by a very large crowd, who came to see the novel mode of hauling coal. In 1815 Stephenson invented the steam blast, which doubled the power of the locomotive, and in 1816 invented a direct and simple communication of power from the cylinders to the driving wheels. Thus it is seen that the railroad, as it is known to-day, grew from two distinct ideas: first, an attempt to improve highways by laying rails to diminish tractive resistance for horse-drawn vehicles, and second, the invention of the locomotive, which was first conceived as an automobile to travel on ordinary roads, and Stephenson's contribution consisted of combining the two ideas as well as in developing the locomotive, which, as a matter of fact, really antedated his efforts.

The discovery that really furnished the cue to the use of locomotives commercially resulted from the experiments by Blackett in 1813 which demonstrated that cars could be propelled along a line of rails by the adhesion of smooth wheels to smooth rails. His experiments were not made on a steam locomotive, however, but on a sort of handcar on which six men operated a windlass, whose motion was communicated to the running wheels. It was found that the adhesion was sufficient to propel the car without causing the wheels to slip.

Up to as late as 1828, however, no locomotive had been built that could do more than propel itself up an "ascent of 1 in 96 at the rate of 10 miles per hour, without dragging any load after it. In the course of two years after, however, such were the improvements made in this engine that it could draw up that ascent a train of cars weighing with their freight 17 tons at 10 miles per hour." * The other rolling stock was also light. Freight cars carried from 2 to 3 tons, and in 1831, on the Baltimore and Ohio, it required a train of eight cars to transport 200 barrels of flour, the loaded train weighing 28 tons.

Railway Beginnings in America. While the credit of originating railways belongs to England, it is interesting to note that John Stevens, in a pamphlet in 1810, predicted the use of steam in propelling locomotives and worked out plans for such a locomotive and the plans and cost of constructing a railroad on which it might be operated. In 1812 he published a pamphlet entitled "Documents Tending to Prove the Superior Advantages of Railways and Steam Carriages over Canal Navigation" in which he stated the possible speed of locomotives might be 100 miles per hour, but that it was probable that in practice the convenient speed might be 20 to 30 miles per hour.

The earliest record of railroad building in America was at Boston in 1807, when a tramway was built for hauling stones. On subsequent railroads, a plan was devised for driving the cars with sails and caused considerable discussion, experiments having shown that cars could be driven by this means at the rate of 12 miles per hour. In this connection, Mr. W. J. McAlpine makes the following statement: † "Our most worthy President, Mr. Horatio Allen, was the first man who took hold of a lever to run a locomotive in America; and I was a small boy and saw it put together. It was called the Lion. . . . Mr. John B. Jervis, on the Baltimore and Ohio Railroad, had two locomotives built, one by George Stephenson at Newcastle-on-Tyne, called the John Bull, and another by Governeur Kemble at West Point, called the Brother Jonathan."

Mr. Horatio Allen brought the first locomotive to America from England in June, 1829. On August 8, 1829, a number of persons were invited to see it start on the road. A short distance from the starting point the rails were laid over a trestle.

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* Ringwalt's "Transportation Systems in the United States."

† Trans. Am. Soc. C.E., Vol. II, p. 57.

As Mr. Allen was not sure as to whether the trestle would hold the locomotive, he decided to ride across alone. "Placing his hand on the throttle valve lever, he moved off amid the cheering of the spectators. As he approached the bridge, he thought whether it were more prudent to go slow or fast; instantly, he decided that if it were to fall it would do so at whatever speed he went, and he might as well go down handsomely, so he put on the steam and disappeared from the view of the spectators. That was the first trip of a steam locomotive in this country." *

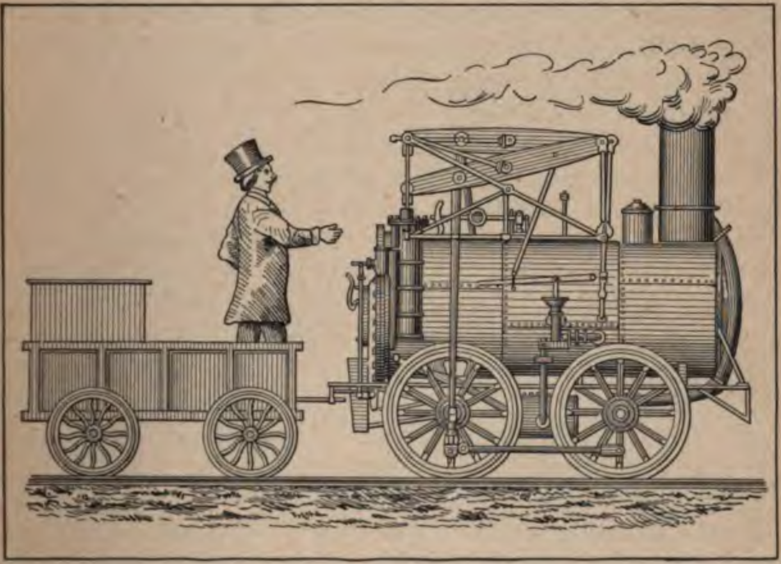

FIG. 1.—The "Stourbridge Lion."

This trial occurred at Honesdale, Pa., on track now owned by the Delaware and Hudson Canal Co., and the locomotive was called the "Stourbridge Lion." See Fig. 1. The total distance run was 3 miles out into the woods and back, making a total run of 6 miles.

Somewhat later in the same year, Mr. Peter Cooper of New York made a small locomotive which was a distinct improvement over the English locomotives, in that it was constructed to adapt itself to curved track and the crank that had been

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* Theodore Allen, Trans. Am. Soc. C.E., Vol. II, p. 61.

deemed necessary to convert reciprocating to rotary motion was dispensed with. The entire locomotive, called the " Tom Thumb" was not larger than a handcar and did not weigh more than a ton. The boiler was about the size of a kitchen boiler and stood upright on the car. The cylinder was only 3½ inches in diameter and the speed was increased by means of gearing. Natural draft was not sufficient to keep up steam and as yet the blower had not come into use, consequently Mr. Cooper resorted to a fan driven from a drum attached to one of the car wheels. Mr. Cooper invited a party of friends to ride from Baltimore to Ellicott's Mills, a distance of 13 miles, and on that trip demonstrated that the locomotive would operate on curved track with ease, thus settling a matter so much in doubt that it cast a gloom over the bright prospect of steam railroads. The return trip was made in 57 minutes, or nearly 14 miles per hour.

" But the triumph of this Tom Thumb engine was not altogether without a drawback. The great stage proprietors of the day were Stockton & Stokes; and on this occasion, a gallant gray of great beauty and power was driven by them from town, attached to another car on the second track—for the company had begun by making two tracks to the Mills—and met the engine at the Relay house on its way back. From this point it was determined to have a race home; and, the start being even, away went horse and engine, the snort of the one and the puff of the other keeping time and time. At first the gray had the best of it, for *his* steam could be applied to the greatest advantage on the instant, while the engine had to wait until the action of the wheels had set the blower to work. The horse was perhaps a quarter of a mile ahead when the safety-valve of the engine lifted, and a thin blue vapor issuing from it showed an excess of steam. The blower whistled, the steam blew off in vapory clouds, the pace increased, the passengers shouted, the engine gained on the horse, soon it lapped him—the silk was applied—the race was neck and neck, nose and nose—then the engine passed the horse, and a great hurrah hailed the victory." * At this point, however, the blower failed, the fire died down, the engine began to wheeze and pant, and again the horse was able to gain the lead and finally won the race into town.

* Latrobe's " The Baltimore and Ohio Railroad—Personal Recollections."

The first commercially successful locomotive in America was "Old Ironsides," the first locomotive built by Mr. M. W. Baldwin, which made its initial run on the Philadelphia and Norristown R. R., November 23, 1832. See Fig. 2.

The incidents related above indicate the first crude beginnings of railways in America. The first regularly operated railroad carrying traffic was the South Carolina Railroad between Charleston Harbor and the mouth of the Oriskany River. The locomotive, "Best Friend," a queer-looking affair with an upright boiler, wooden wheels and iron tires, had been built at the West Point Foundry. The road was nominally opened to traffic on January 15, 1830, but the first anniversary of that date witnessed the real celebration of its opening, for "Best Friend" was not completed until the summer of that year. Not long after the celebration, "Best Friend" was destroyed through the ignorance of the negro fireman, who held down the safety valve because its continual popping off annoyed him. It may be stated, in passing, that the negro was probably the first railroad casualty victim in America. In 1834, this road boasted of 135 miles of track, with grades not exceeding 30 ft. per mile and with curves of large radius. The cost of the line was less than $13,000 per mile, including equipment.

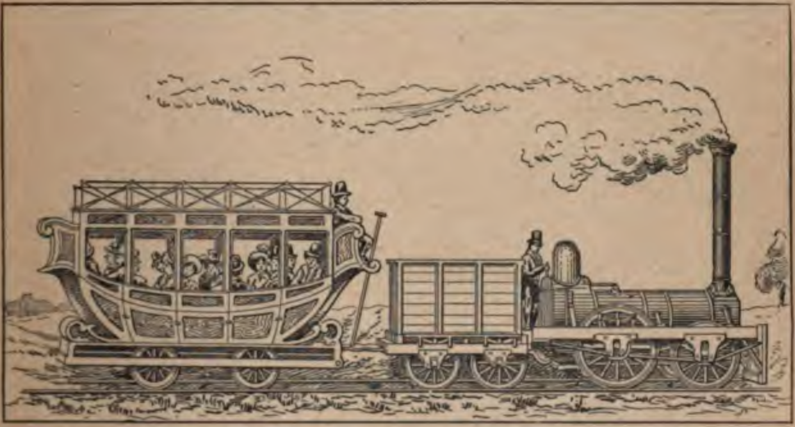

FIG. 2.—"Old Ironsides."

Early Railroad Track. On the first railways, the rails consisted of longitudinal timbers laid on cross-ties or on stones.

Later cast-iron rails supported at the joints by blocks were introduced and some time afterward straps of iron were attached to the longitudinal timbers, but it was not until 1789 that "edge rails" were employed. The first question that arose in connection with the shaping of a special rail was whether the flange for preventing derailment should be on the rail or on the wheel. Fig. 3 (*p*) shows an old flange rail, called a *tram plate*, the flange sometimes being placed on the outside and sometimes on the inside of the rail. This type was superseded by the "edge rail," or a bar of iron placed edgewise, and with this improvement the tramways became *railways*. Some of the forms given to early rails are shown in Fig. 3, Section (*e*) being a French section, (*f*) American, and the remainder English. These sections indicate in a general way the evolution of the modern T-rail, which was invented by R. L. Stevens, Chief Engineer and President of the Camden and Amboy Railroad.

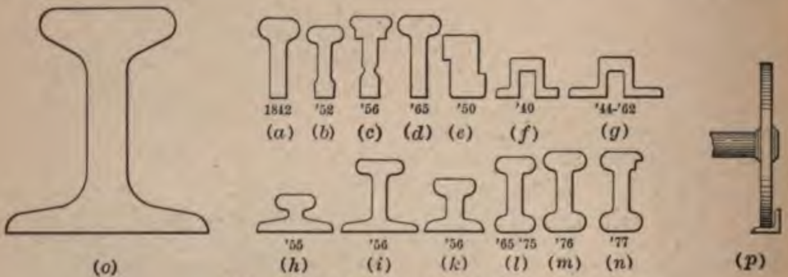

FIG. 3.—Early Railroad Rails.

Many railroads in the beginning adopted the plan of placing the rails continuously on longitudinal sleepers, called the "continuous bearing system," but most roads adopted the plan of supporting the rails at intervals in iron chairs that rested on transverse sleepers, although in some instances, the chairs were placed on blocks of stone.

The split switch was an early invention and was built in essentially the same form as is found to-day. By means of it, railroad tracks were enabled to branch from another line.

As stated before, the gauge of track adopted from the first had been 4 ft. 8½ ins., because that was the width of tread of most of the carriages to be hauled over the roads. When special carriages had been constructed, however, some question arose as to the proper width of gauge. Mr. Jonathan Knight, Chief Engineer of the Baltimore and Ohio Railroad, made an elaborate mathematical analysis of the problem from which he concluded that 4 ft. $9\frac{1}{4}$ ins. was the proper width of gauge. This analysis was based on certain assumptions as to diameter of wheels, height of center of gravity, proper play between wheel and rail, etc., none of which were uniform, and very naturally different roads and different countries adopted various widths of gauge. Later, when the movement toward making connections between roads became general, a fierce strife, sometimes called "the battle of the gauges," arose over which gauge should be adopted as standard. This led to a governmental inquiry in 1846 on the basis of which the present standard gauge of 4 ft. $8\frac{1}{2}$ ins. was adopted.

Operating Conditions on Early Railroads. The crudities of operation on the early railroads were entirely commensurate with the character of the track construction and the equipment. At first, the engineer collected the passenger fares and the fireman handled the baggage and local freight. There was no conductor, although later, important trains were in charge of a responsible officer, called the captain of the train. His position was analogous to that of the captain of a sailing vessel, being in responsible charge of the train's movements and of its passengers and cargo throughout the journey of somewhat uncertain duration. Early minutes of the meetings of the board of directors of the Michigan Central Railroad as well as of others, show that the train captain or conductor was elected by ballot of the board. Trains usually put up for the night as had been the custom of the old stage coach. Headlights were first introduced on the Boston and Worcester in 1840, and previous to that time night operation was commonly effected by pushing a car ahead of the engine on which a fire was kept burning.

The telegraph was not in use for railway service until 1850. There was no steam whistle or bell. Strict adherence to the time schedule was about the only method by which trains could be safely operated and on account of the frequent derailments and other accidents complete satisfaction did not result. On busy roads, locomotives were kept in readiness with steam up prepared to go to the relief of belated trains. When the relief engine started out to meet the delayed train, there was no knowing whether the latter would be found around the first curve or 20 miles away, for the only knowledge to be had at headquarters was that the train had not arrived on schedule time. Therefore, on single-track road, it was necessary to flag around every curve.

The railroads generally earned more from passenger fares than from freight. The freight rates were so high that many articles now transported over the railways could not bear the cost of the movement. On the Baltimore and Ohio, the freight rate was 6 cents per ton mile and the Petersburg Railroad in Virginia was forbidden by its charter to charge more than 12½ cents per ton mile. In 1840, the flour rate from Pittsburg to Philadelphia was $1.55 per barrel, which amounted to a little more than 4 cents per ton mile. The flour rate on the Michigan Central in 1838 was 12½ cents per ton mile. The passenger fares on the Michigan State Railroad in 1840 was 8 cents per mile, while the Central Railroad and Banking Company of Georgia was forbidden by its charter to charge more than 5 cents. In 1837 the following rates were in effect for passenger service: *

Baltimore and Ohio	3 cents
Baltimore and Washington	6 cents
Boston and Providence	5 cents
Boston and Lowell	3½ cents
Mohawk and Hudson	5 cents

When a movement became general to operate through trains by connecting various short lines, much difficulty arose concerning the choice of gauge and other matters. At Erie, Pa., a serious strife occurred lasting over a year in which the townspeople bitterly opposed uniting the two roads which passed through that city, on the ground that Erie would be changed from the important status of a terminus to that of a way station and that the hotel and bus business would be ruined.

Whatever the difficulties attendant upon early railroading there were some who foresaw the remarkable influence the

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* Ringwalt's "Development of Transportation Systems in the United States."

building of such railways was to have upon the development of the country. On July 4, 1828, when the venerable Charles Carroll of Carrollton, Md., the only survivor at that time of the signers of the Declaration of Independence, "laid the first stone" in the construction of the Baltimore and Ohio Railroad, he turned to some of his friends and remarked that he considered that one of the greatest acts of his life, second only to the signing of the Declaration of Independence, if indeed it were second to that.

Railroads over the Alleghenies. Previous to the middle of the nineteenth century, the railroads were chiefly in the experimental stage and did not exercise any great influence on the development of the country. There was practically no interstate traffic as it exists at the present time. There were but two transportation routes from the Central West to the Atlantic seaboard, viz., the Erie Canal and the state route through Pennsylvania. The latter comprised the Columbia and Portage railroads and consisted of part canal and part railroad.* The Columbia road extended from Philadelphia to Hollidaysburg at the eastern base of the mountains, while the Portage railroad extended from Pittsburg to Johnstown at the western base of the mountains. The former consisted of a railroad along the Susquehanna from Philadelphia to Columbia (82 miles) and a canal from Columbia to Hollidaysburg (172 miles). The latter consisted of the Portage railroad from Hollidaysburg to Johnstown (36 miles) and the canal from Johnstown to Pittsburg (104 miles). The Portage railroad over the range of mountains was one of the wonders of the time, consisting of eleven levels and ten inclines. While the Portage railroad accomplished the much-desired end of connecting the waters of the Ohio and Delaware rivers, yet it proved to be too slow and cumbersome and too expensive to meet the demands of the trade. It was in operation from 1834 to 1854 and cost the state of Pennsylvania 14½ million dollars to construct it. The annual traffic over the Portage route was about 20,000 tons, whereas that over the Erie Canal was 1,000,000 to 2,000,000 tons.

In 1828 the Baltimore and Ohio was begun with the hope of bringing the traffic from the Mississippi valley to Baltimore, but the road was not completed until 1852. Before the middle of the century, therefore, the immigrants that passed over the mountains for the most part had done so by means of horses and wagons. Nevertheless the rich lands of the valleys west of the Alleghenies had so filled up that the center of population moved westward from Baltimore, where it was in 1790, to a point west of the mountains in 1840. In consequence of this increase in population, a large amount of grain and other produce had to be sent to the eastern ports. This had very naturally followed the water route via the Great Lakes and the Erie Canal. In 1842 a railroad was opened between Albany and Buffalo; in 1848 one was completed from Lake Erie to Cincinnati; the Cleveland and Pittsburg was put into operation in 1852 and a line was opened between Buffalo and Toledo the next year. The Michigan Central and the Michigan Southern were opened in 1852. In 1851 the Hudson River Railroad was opened and the Erie was completed between the Hudson and Lake Erie. The Pennsylvania reached the Ohio River in 1852 as did also the Baltimore and Ohio.

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* The "Pennsylvania Railroad," W. B. Sipes.

About this time the railroads began to compete with the canals. In order to protect the Erie Canal, all freight over the New York Central Railroad was subject to canal tolls at first. However, when the Erie was completed, the former railroad was relieved of its burden of canal tolls, and then from 1853 to 1859, there was a fight for supremacy between the railroad and the canal which resulted in the railroad's practically vanquishing its rival.

The successful competition of the railroads with the canal marked the beginning of the expansion and development of the interior country by the railroads. The Pennsylvania Railroad was extended to Chicago in 1858 by the completion of the Pittsburg, Ft. Wayne and Chicago R. R. Between 1850 and 1860 the railroad mileage of the country increased 240 per cent. In the same decade, the center of population moved westward 81 miles, the greatest stride it has ever made.*

In all this building, one feature stands out prominently even in a most cursory glance over the history of American railroads, namely, the railroads from the first were built from the seaboard toward the interior. Their promoters lost very little effort in attempting to parallel the coast line, thereby entering into competition with marine shipping. Moreover, one of the chief functions of the early railroad as well as of those of to-day was to bring the produce from the interior to the coast cities, consequently, they naturally struck off directly toward those parts which the waterways did not reach.

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* "Railway Development in the United States," W. D. Taylor, Trans. Am. Soc. C.E., Vol. LXXIV, p. 94.

Railroads in the Central West. Previous to the year 1854 when the Rock Island Railroad reached the Mississippi River, the produce from the region beyond that stream as well as that along the streams tributary to it had reached shipping ports by way of the rivers. The Rock Island was soon followed by the Galena and Chicago Union (Chicago and Northwestern), the Chicago and Alton in 1855 and the Chicago, Burlington and Quincy in 1856. In the North, the Milwaukee and Prairie du Chien and the Milwaukee and La Crosse, built in 1857 and 1858, respectively, connected the Mississippi River with Lake Michigan. The Illinois Central, which was built to develop the prairies of Illinois, operated its first train in 1856. In plan, it resembled a great Y with the end of its right prong at Chicago and the end of the left prong at Dubuque, Iowa, and the end of the stem at Cairo at the junction of the Ohio and Mississippi rivers, the fork being at Centralia. Its object was to bring traffic to Chicago to be sent eastward over the Great Lakes, but by the time it was completed, the business of the lines extending eastward had grown to such proportions that the prospective traffic did not materialize, and consequently the real prosperity of the line was delayed until Chicago itself became a primary market and other extensions of the road had been made.

Mr. J. J. Shipman, Chief Engineer of the Alton and Sangamon Railroad (Chicago and Alton), in reporting on the proposed location in 1852, gave an unusually lucid and comprehensive analysis of the probable future of the road, from which a few brief paragraphs may be extracted, since they portray so well the railway situation existing at that time.*

"In looking at the prospective business of the Western Roads we believe a much more correct estimate can be found of its extent from a general view of the productiveness and course of trade in that section than from the most elaborate compilation of statistics drawn from existing data. The amount of production and the extent of movement of property are now subordinate to the *means* of transportation. Some of the most fertile portions of Illinois are now valueless simply for the want of a suitable outlet to a market. Many sections that are destined to be the most flourishing are still covered with forests. In many portions of the state, the surplus of grains will not bear the cost of carriage to navigable waters. The rivers of Illinois, the present route of commerce, though invaluable in the absence of railroads, are for a considerable portion of the year not available for transportation. From the commerce that has already been developed, we can form but a faint idea of what is to come, when the suitable means and instruments have been provided."

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* Trans. Am. Soc. C.E., Vol. LXXIV, p. 147.

In attempting to form a definite estimate of the probable traffic, Mr. Shipman stated: "Making the application with the substitution of 22 inhabitants to the square mile instead of 15 (which, under the census of 1850, we find to the square mile along the Alton and Springfield Railroad), and we have the following result: Length of road, 72 miles. Number of square miles within 15 miles of the road, 2160; population, 50,160—farmers engaged in cultivation of the soil, 8360; corn produced, 12,540,000 bushels; estimated amount of corn, or its equivalent to pass on the road, 5,573,333 bushels;—or 666⅔ to the family, and amounting to 167,535 tons, which at *four cents per ton per mile*, averaging the transportation at one-half the length of the road, 38 miles, at $1.52 per ton, will yield a revenue of $254,563.20. . . .

"The local travel of the same population will be an item of some importance. They must be considerably scattered and if they associate at all, they must use the road. Each head of a family averages five journeys of 60 miles each, or 300 miles per annum, for the whole household. It will cause the road to carry one passenger 18,000,000 miles, which, at 3 cents per mile, is $540,000. This would amount to $9 for each family per annum. If we reduce it one-half, there can be no doubt of the other half being made up by the other local passenger and freight business, such as those living without the limit of 12 miles, of citizens of other states visiting the stations, and the thousands of trips from the termini to the interior. It seems safe then to let this item stand. Applying this estimate to the 8360 families on the line of the Alton and Sangamon, and we have a revenue of $75,240 from this source." . . .

"In conclusion, I have thought it would be desirable to place before our Stockholders a brief view of the various roads under construction or in contemplation, which will exercise an influence on the prosperity of the state, and necessarily upon that of our roads. So far as competition may or does exist, I consider it salutary and tending to the prosperity of all the different corporations, who will be impelled to do better service to the public, and thus secure more permanently their own interests than they would otherwise be induced to do. And it is certain that such rivalship, though salutary, must exist more in appearance than in fact, for the natural increase in business and wealth growing out of the construction and operation of these roads, together with the increase in population, will, by adding to the general prosperity, benefit the whole.

"On reference to the outline map herewith, it will be perceived that at Springfield we connect with the Sangamon and Morgan Railroad, which has for several years been in active and profitable operation, a distance of 57 miles. In addition to the local business at Springfield, I think we may look for a large business from the thriving farmers along the line of the road, as well as from the beautiful and populous village of Jacksonville and its vicinity. The surplus crops of the vicinity are determined north or south as the market rules. For a southern market, they would find it for their interest to send over our road to Alton and St. Louis, and for a northern market, by our road to Bloomington, and thence by the Central Railroad and the Rock Island Railroad to Chicago; freights in return would take the same course, and we should contribute as much to the business of the road, if not more, than they would obtain otherwise. At the western end of the Sangamon and Morgan road, the extension toward Quincy is under contract for some 30 miles; and its early completion may be expected. Eastward from Springfield, following the old line of the Northern Cross Railroad, arrangements are in progress to enable a connection to be made with the Central Railroad at some convenient point. I feel quite certain that this design will be carried out, and doubt not we shall receive a large addition to our business from it. It seems that so far as the course of business will be affected by the opening of our road to Springfield, it will reverse the direction of the business on the Sangamon and Morgan Railroad, so that the balance of the business will tend towards Springfield rather than to the Illinois. Among other reasons for this belief, it may be remembered that the time from Springfield to St. Louis is now by railroad and steamboat thirty-four hours; on the opening of our road, it would not exceed five hours. If the Sangamon and Morgan road should carry their passengers for nothing, they would still have 19 hours against them. . . .

"Following our line to Pekin and Peoria, we find the only crossing on the Illinois by a bridge; and having crossed it, we unite with the Peoria, Burlington and Oquawka Railroad, through the center of the Military Tract, one of the richest and most thickly settled portions of Illinois. In addition to this, following the line of the Illinois River northward, we command the business on both sides of this river for 60 miles. I hesitate not to say this because we are nearer St. Louis by 43 miles of distance and 15 hours in time, than by the river in the best stage. The average charge for freight will be less than the best steamboat rates, one season with another. This is a matter which is susceptible of demonstration. Omitting, therefore, all lines which may be said indirectly to connect with us, we may consider the connections formed by our extended lines as equal to 663 miles. If, then, the reasoning in the prefatory remarks to this report is reliable, every foot of this extended line will be fully and profitably engaged, and the main branches where the trade will concentrate will be compelled to make arrangements for the transaction of a business unparalleled for its importance and extent in the history of commerce."

The map referred to by Mr. Shipman shows the railroads built and building in Illinois in 1851, and includes the entire state of Illinois, which may be termed, not at all improperly, the heart of American railroad systems of the present day. The following roads are shown on this map:

Galena & Chicago R. R.		183 miles
Rock Island R. R.	about	110 "
Burlington & Peoria R. R.		92 "

Sangamon & Morgan R. R., extending from Quincy to Springfield...........	115 miles
Alton & Sangamon R. R., extending from Alton to Springfield	72 "

In the growth and development of the entire Middle West, the railroads played an extremely important part, as is indicated by the report of Mr. Shipman.

Transcontinental Railroads. Mining operations in California and in Colorado gave a great impetus to the westward march of the army of settlers and explorers. Even when railroad building was in its infancy in the East and Middle West, towns and colonies of considerable size were flourishing in these western regions. By irrigation where necessary, the hardy pioneers were producing their own food supply and were bringing clothing and other needed articles overland by stage. Very few dreamed that the railroads would soon be pushing westward over the plains, through the mountains even to the coast. Indeed, it was freely predicted that the absence of timber, the prevalence of deep snows and many other obstacles would be insuperable. However, as early as 1832, a writer in *The Emigrant*, ? at Ann Arbor, Mich., with profound apologies for suggesting so visionary a scheme, proposed the construction of a rail route up the Platte, along the Snake, and down the Columbia rivers to the Pacific Coast, a route that was followed to a great extent by the Union Pacific when it was constructed thirty years later. During the decade prior to 1850, when railroad agitation was rife, Mr. Asa Whitney, a wealthy New York merchant, urged the building of a Pacific railroad. He made numerous explorations at his own expense and memorialized Congress repeatedly on the subject. He had spent some years in China and saw clearly the advantages resulting from opening up a route directly from the Orient to the east coast of the United States. Mr. Whitney spent his entire fortune in promoting the enterprise and later had to peddle milk in the city of Washington for a living.*

While Mr. Whitney's efforts brought nothing but disappointment and poverty to himself, they were not in vain, for he greatly interested the people generally in the scheme. One magazine stated in 1854 that "exploration has convinced every one that there are several ways of connecting the Atlantic and the Pacific by ordinary railways. The obstacle to be surmounted is not the location of a route, but what route to choose of the number already located."

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* "The Union Pacific Railway," J. P. Davis.

The chief difficulty lay not so much in the topography of the land as in the unproductiveness of the region to be traversed and in the great distance over which supplies and materials had to be transported. To stimulate the undertaking, the Federal Government offered a liberal bounty in money, amounting to $30,000 per mile of line and a grant of land of every alternate section for 20 miles on either side of the right of way. Two companies accepted the conditions offered by the Government, the Union Pacific beginning at Omaha, Nebraska, and extending westward, and the Central Pacific commencing at San Francisco and building eastward. The Pacific Railroad bill in its final form passed Congress in 1864, work was begun at San Francisco the same year and at Omaha two years later, and the entire road to the coast was finished by the meeting of the lines at Promontory Point, Utah, May 10, 1869. The Chicago and Northwestern had completed its line to Council Bluffs from Chicago in 1867, consequently, upon the joining of the two Pacific railroads, a rail route extended from New York to San Francisco.

In contemplation of the Pacific Railroad, the Government had made surveys in 1852–4 of possible passes over the mountains. The engineers in charge of these surveys reported that five possible routes were open. Since that time, these have been occupied as follows, in order, beginning with the farthest north: Northern Pacific, the Union Pacific, the Denver and Rio Grande, the Atchison, Topeka, and Santa Fe, and the Southern Pacific. The Northern Pacific was chartered in 1864 and completed in 1883 after a desperate financial struggle. The Southern Pacific established a through route in 1882 by connecting its line from San Francisco, which had been organized as a subsidiary line to the Central Pacific, with the Texas Pacific near El Paso. The Atchison and Topeka R. R. was chartered in 1859 and was developed as an agricultural road in Kansas. Later it was extended along the old Santa Fe trail up the Arkansas River and over the Raton Mountains, at which time its name was changed to the Atchison, Topeka and Santa Fe. Still later, in 1888, this line was extended on across the continent to San Francisco. More recently, the completion of the Great Northern and the Chicago, Milwaukee and St. Paul lines to the coast gives two additional transcontinental railroads.

Inter-connecting Railroads. The main lines previously mentioned are east and west roads, and they form sort of a framework for the whole railroad system of the country. They are like the primary triangulation system to which other surveys are connected. While they were being located and constructed, as well as afterward, a vast number of roads of various lengths and importance were built to serve those regions that were untouched by the main trunk lines. In this group were the many ramifications of the Rock Island and of the Burlington, the Kansas Pacific, Missouri Pacific, Iowa Central, Wisconsin Central, Chicago and Eastern Illinois, Big Four, and a host of others. They were just as important in the development of the country as were the longer lines, but they represent to a certain extent, a different purpose in railroad building. They care for the intermediate and, to a considerable degree, to the north and south traffic. To even the casual observer, it is obvious that the predominating trend of traffic in this country has been, and is now, east and west. Very few roads have been built primarily to care for the north and south commerce. A few such, however, have been built, notably the Chicago and Eastern Illinois, the southern extension of the Illinois Central, the Minneapolis and St. Louis, the St. Louis and Iron Mountain, the Kansas City Southern, the Frisco, the St. Louis and Southwestern, the Missouri, Kansas and Texas, the Mobile and Ohio, the Southern Railway, the Colorado and Southern, the Oregon and Short Line, and several others.

Southern Railroads. No trunk lines have been built in the South which are comparable in length to those of the North, the lines in that region for the most part taking on the character of community railroads similar to those local roads mentioned in the last paragraph. However, railroad construction was begun in the South at an early date, as stated previously, when the South Carolina Railroad was opened for business in 1830. The Georgia Railroad was built in 1839, the Central of Georgia in 1840, the Western Railway of Alabama in 1853, the Nashville and Chattanooga in 1857; the Mobile and Ohio was opened from Mobile to Columbus, Ky., in 1859, and in the same year the New Orleans, Jackson and Great Northern, together with the Mississippi Central, furnished a continuous line from New Orleans to Jackson, Tenn. The Louisville and Nashville joined those two cities in 1859 and was extended to Memphis in 1861. During the Civil War and the Reconstruction Period, railroad building was at a standstill in the South. The Illinois Central was the first to enter from the north, opening its line for traffic between Chicago and New Orleans in 1873. The Louisville and Nashville extended its lines to the southward about the same time, reaching Mobile in 1880.

Growth of Railway Systems. From the preceding brief historical summary, the piecemeal character of the growth of American railways is apparent. They were constructed largely as community railroads wherever local pride and enterprise were sufficiently strong to make possible the procuring of necessary funds. Many were organized as short roads 20 to 100 miles in length, while others were organized as extensive lines, but funds becoming exhausted, not a few of these ended within a short distance of their point of beginning. In the last quarter of the nineteenth century, an epoch in industrial history when combination and huge organization was the chief characteristic of commercial activity, large holding corporations were organized to take several such small railroads under control, the large roads bought up many small ones and pieced them together to form large systems, both processes giving rise to the extensive and complicated railway groups of the present day. For example, the Chicago, Burlington and Quincy Railroad comprises about 60 or 70 such small roads, averaging about 100 miles in length, but the majority of them being less than 50 miles long. The Burlington owns the majority of stock of the Colorado and Southern, which in turn owns the Colorado Midland, the Colorado R. R., the Ft. Worth and Denver City, the Gilpin R. R., the Trinity and Brazos Valley, and the Wichita Valley, and the last named owns the Wichita Falls and Oklahoma, the Abilene and Northern, and the Stanford and Northwestern. To show further the corporate complexity of railroad ownership, it may be stated that the Burlington is owned equally by the Great Northern and the Northern Pacific railways. The case of the Burlington, moreover, is not exceptional. Many of the American railroads are as complicated or more so than it is.

As stated above, the railways were laid out piecemeal, without any general scheme for the whole. Like Topsy, they "jus' growed." The process of combining them into such systems as the natural trend and movement of traffic required, as described above, has done much to overcome the difficulties resulting from the haphazard scheme of development. The railways of most European countries, notably those of France, were built after the countries were completely settled, the location of cities and towns fixed and the natural traffic courses determined, and consequently, they could be designed according to a comprehensive and adequate scheme of transportation. American railways were built without such a plan being possible, owing to the unsettled condition of the country to be served. However, it seems probable that a further organization of the railways of this country into some comprehensive scheme of transportation system will occur at some future time in order to effect the economies necessary in the present state of industry.

The Public Character of Railways. One prominent feature that stands out in a study of the history of the origin and growth of railways, and one to which reference should be made in this connection, is their essentially public character. Railroads had their origin before the locomotive had been thought of, as has been seen, in an effort to improve the public highways by laying down timber wheelways. These wheelways were still the public highways and so it can be stated not inappropriately that the highway was the ancestor of the railway. Later, when the steam locomotive was invented, it was substituted as the tractive power instead of horses. Railway companies were organized on the same basis as turnpike companies, of which there were about 800 in America in 1812. In most European countries, the railways have never been separated from the state, but in America they assumed a status of almost private corporations. Recently, however, the public nature of railroads has been recognized in this country, and governmental control has become more and more definite and complete with each session of Congress and each term of the Supreme Court.

Retrospect. As stated at the beginning of this chapter, the development of the vast areas of the United States has been inseparably interwoven with the growth of the railroads. Almost within the span of a generation, this greatest of all organized industries has developed from its genesis to its present mammoth proportions. In 1910 there were 2037 different steam railways in America, and in 1912 there were 2165. The following table shows the growth of the mileage:

	Miles		Miles
1830	237	1900	192,940
1835	1,098	1910	238,609
1840	2,818	1911	252,970
1850	9,021	1912	256,162
1860	30,635	1913	259,089
1870	52,922	1914	261,554
1880	93,671	1915	262,547
1890	159,271		

The liberal land grants of the Federal Government greatly stimulated railroad building. In all 155,000,000 acres of land were given to railways, practically all of the large lines west of the Mississippi having been aided in this manner. Various inventions from time to time gave added impetus, among which may be mentioned the discovery by Blackett in 1813 that the adhesion between wheels and smooth iron rails was sufficient to cause self-propulsion; the invention of the flexible wheel base by Peter Cooper which would permit locomotives to pass around curves; Ross Winans' invention of the four-wheel truck and his anti-friction journal; the invention of the Bessemer process of manufacturing steel rails by which they were greatly cheapened and improved in quality; the invention of the air brake by George Westinghouse; the development and use of the cast wheel in locomotive and car construction; the invention of the electric track circuit by Wm. Robinson in 1872.

PART A

RAILWAY ECONOMICS AND LEGISLATION

CHAPTER II

RAILWAY ORGANIZATION

Nature of a Corporation. Building a railroad is altogether too large an undertaking to be handled by an individual, owing to the amount of capital required and the risk involved. It is necessary, therefore, that a number of persons unite their resources and share the risks necessary to the accomplishment of such an enterprise. These objects are effected by forming what is called a corporation. A corporation may be defined as a collection of natural persons united by the authority of the law under a special corporate name, with the capacity of perpetual succession and acting in many respects as a natural person. A corporation is in fact a legal entity, or, as it is termed frequently in law, an artificial person. It has an existence separate and distinct from that of the members who compose it. It has a definite domicile or place of doing business; it can sue and be sued at law; it can hold and convey property; it is liable for the torts of its servants and may be fined for misdemeanors, and in many other respects resembles the character of a natural person. The members that compose the corporation are not personally responsible for the debts or other obligations of the corporation beyond the amount of their stock, and the life of the corporation does not cease at the death of the incorporators. Since a corporation is a creature of the law, its powers are set forth in the instrument of its creation, namely, its Charter.

The Charter. The origin of the charter idea relates back to the time when certain persons were given special rights by the king to do some act or enjoy special privileges which were not granted to his subjects generally. A charter under our government is a grant of special privileges to certain individuals for the carrying on of a specified business. In the famous Dartmouth College case, the Supreme Court of the United States held that a charter was a contract between the state and the corporation which could not be broken or altered by one party without the consent of the other. However, as such a doctrine would effectually prevent the public from controlling its own creatures and reforming grave abuses of corporate power, nearly every state has passed statutes that no charter should thereafter be granted which would not be subject to alteration or repeal by the state under certain conditions. In fact, nearly all states have general corporation laws under which corporations are formed and the formation of such a body is a matter of routine compliance with the specified legal forms rather than a special grant by the legislature.

The variations naturally existing in the corporation laws of the different states have given rise to queer conditions in regard to the homes or domiciles of some railroad corporations. Some railroads are incorporated in states where but a small portion of their operations are conducted, and indeed, in a few instances, the articles of incorporation were taken out in states where the companies had no mileage of track whatever. For example, the Northern Pacific Railroad, whose lines total about 6000 miles, was incorporated in the State of Wisconsin in view of the construction of an unimportant line in that state, which, as a matter of fact, was never built. A railroad in general might be incorporated in any state through which it proposed to extend its lines.

While the charter grants certain designated powers, it also grants many others by implication, commonly called implied powers, which are necessary for conducting the business for which the corporation was primarily organized. Besides the right to do business as a common carrier (q.v.), a railroad company acquires by its charter other corporate rights, among which are the following:

a. The right to use a corporate name.

b. The right of perpetual succession.

c. The right to acquire, hold, convey, possess and dispose of corporate property.

d. The right to appoint corporate officers and agents.
e. The right to establish by-laws for the government of the corporation, its officers and members.
f. The right to sue and be sued.

If a corporation should contract beyond its powers either express or implied, the contract was formerly held to be voidable as being *ultra vires,* but at the present time, a contract with a private corporation, such as a railroad, cannot be voided on this ground. From the above considerations, it may be seen that a railroad's charter is its authority for doing business, and in general it may perform almost any act connected with such business, being responsible to the state in the exercise of its implied powers.

State Laws Governing Railway Incorporation. The conditions under which railways are incorporated vary greatly in different states, as has been mentioned. The law usually provides a minimum number of incorporators, specifies the character of stock to be issued and the conditions of issuing the same, to whom to make application for the charter, the mode of electing directors, and others. In Kansas, for example, the minimum number of incorporators is five, while in Colorado it is three. The general statute also specifies the general powers of the proposed railroad company and indicates its obligations. Perhaps one of the most equitable of the laws relating to the incorporation of railways, and one that is in a sense typical of all, is the New York law, some of whose provisions are:

1. The number of railroad incorporators must be fifteen or more.
2. The incorporators shall file a certificate that shall set forth the following facts:
   a. Name of the railroad, its length and termini.
   b. Number of years it is to continue.
   c. The kind of railroad.
   d. The names of the counties to be passed through.
   e. The amount of capital stock (not less than $10,000 per mile of line).
3. Common and preferred stock must be defined.
4. There must be at least nine directors.

5. The name, address and number of shares of each incorporator must be stated.
6. At least 10 per cent of the capital stock must be paid in cash.

Officers. The business of a railroad, like that of any other corporation, is transacted by a board of directors and such other officers and agents as may be necessary, any of whom may bind the company by their acts within the scope of their authority. The Board of Directors has the power to bind the corporation by any act or contract within the powers granted by the charter, being responsible only to the stockholders. The other officers of the company usually include a president, one or more vice-presidents, a secretary, a treasurer. The Board of Directors is elected by the stockholders, while the other officers are appointed by the Board of Directors itself, and may or may not be members of that body. The officers being intrusted with the affairs and funds of the stockholders stand in a fiduciary relation to them and are required to exercise even greater care concerning these matters than they would concerning their own business, and are personally responsible for any misapplication of funds. There is a growing tendency to hold the officers responsible jointly with the corporation for the torts and misdemeanors of the latter.

Promotion. Usually the idea of building a railroad is conceived by one person, or at most by a small number. This person takes the lead in finding the requisite number of incorporators, in securing the charter and in seeing to it that the company is regularly incorporated. Such a person is called a *promoter* The promoter issues a prospectus, or paper scheme of the project, setting forth the possibilities and booms the enterprise generally In general, a promoter is responsible for his own acts previous to the organization of the corporation, unless the latter adopts them as its own after such organization is complete. The prospectus which the promoter circulates may be optimistic, even of a roseate hue, but must contain no positive misstatement of facts, as such would constitute a fraud. The promotion involves also the securing of the necessary paid-up subscription of capital stock and of interesting the public in the enterprise.

Capital Stock. The *capital* of a corporation is the fund with which it conducts its business and embraces all its property, both real and personal. The *capital stock* is the amount of capital that the charter requires to be subscribed, and remains unvaried, unless changed by a legislative act. It is the amount of capital with which the company attempts to begin business, and to the public at large, it signifies the amount of means contributed to this end and is therefore commonly accepted as a measure of the credit to which the corporation is entitled. The amount of capital stock issued by a railroad depends upon the probable amount required to build and equip its lines.

A *share of stock* is the right to participate in the surplus earnings of a corporation in the way of *dividends* and ultimately to share in the net assets remaining upon dissolution. A *stock certificate* is a written acknowledgment by the corporation of the rights and interests of the *stockholder* in the corporate property and franchise. *Full paid stock* is stock the full value of which has been paid in cash or in other property and is not liable to further assessment. *Common stock* entitles the holder to a *pro rata* division of the profits, if there are any, after all prior obligations have been met. *Preferred stock* entitles the holder to a certain per cent of dividends before common stock is awarded any. However, dividends are not guaranteed on preferred stock and its dividends are limited to the amount stipulated, hence, it sometimes happens in the case of very successful railroads that the common stock is more valuable than the preferred. Preferred stock is sometimes issued as first and second preferred stock. When the capital stock is increased without any definite property value being added, the stock is said to have been "*watered*." The object of such procedure is to decrease the value of the stock already outstanding and it results in a smaller percentage being paid in dividends, although the actual amount may remain unchanged. Stockholders are liable ordinarily to the full extent of the par value of their stock and no more, although in certain classes of corporations this provision has been modified. For example, the stockholders are liable for the debts of the corporation to the extent of the unpaid balance of their stock, but, of course, if the stock has been paid in full, they are exempt from further liability. However, a corporation has a right to issue *non-assessable stock* below par which shall be exempt from further assessments on the part of the corporation, but non-assessable stock does not relieve the holder from full responsibility to subsequent creditors in the event of insolvency. Shareholders have a right to *transfer* their stock to anyone who is competent to hold the same. The transferee takes the place of the first shareholder, assumes all his rights and is responsible for all his obligations.

Funded Debt. The funded debt consists of those obligations that require the payment of a definite rate of interest, and consists essentially of bonds. Bonds are promissory notes issued under the corporate seal when the corporation desires to borrow money. Instead of borrowing of individuals, however, the bonds are made payable to the bearer and are sold on the open market, sometimes above their par value and sometimes below. Interest on bonds as well as the principal must be paid when due, and if interest or principal is not paid when due, the railroad is declared insolvent and the creditors proceed to take the property of the company in satisfaction of the amounts due them. The total bond issue is essentially the funded debt and it is secured by mortgages on the property or income of the company. *Debenture bonds* are bonds that carry with them as collateral a lien on the income of the railroad instead of its physical property. Strictly speaking, bonds are not a part of the capital stock of a railroad, but in stating the total capitalization, the bond issue is generally included. This is in accord with the statement of Mr. Henry C. Adams, formerly statistician of the Interstate Commerce Commission, to the effect that capitalization means " the amount of active capital to be supported by freight and passenger rates," and with the present definition by that body, viz., " By railway capital . . . is meant the aggregate of securities issued." The total funded debt includes mortgage bonds, collateral trust bonds, equipment trust obligations, plain bonds, debenture bonds, notes, and miscellaneous funded obligations.

In recent years, some of the larger railway systems have made immense issues of bonds secured by mortgages, with a view to refunding old mortgages and for making improvements. In 1911, the Great Northern created a mortgage of $600,000,000 and recently the Baltimore and Ohio made a similar issue, and four others, the Northern Pacific, the Erie, the New York Central, and the Southern have made issues of $500,000,000 or more. As related in the first chapter, most of the large railway systems of the country are composed of a number of small lines, and each of these has its own bonds outstanding. The Southern Railway, for example, was formed in 1893 by consolidating more than thirty separate companies. The Erie had second, third, fourth and fifth mortgage bonds outstanding, and this new issue which will refund the old issues are intended to strengthen the credit of the railroad.

Capitalization of the Railways of the United States. The railways of the United States have cost an immense sum of money, but, unfortunately, the amount of this cost is not a matter of record. Records of the cost of many roads were not kept systematically, owing to the unscientific method of building them, and the records of others have been lost in the years that have intervened since their construction. However, the capitalization of a railroad does not apparently bear any direct relation to the cost of construction, nor even to its present value as it might be determined by a board of appraisers. That this is true is indicated by the figures given below, which show the cost of reproduction, the present value, and the capitalization of railroads in four states where such an appraisal has been made.

	Cost of Reproduction.	Present Value.	Capitalization.
Washington........	$194,057,240	$175,797,025	$101,582,000
South Dakota......	106,494,503	91,695,192	109,444,000
Minnesota.........	360,961,548	309,706,514	300,027,576
Wisconsin.........	296,893,322	240,718,711	225,000,000

About one-fifth of the capital stock and funded debt is owned by the railways themselves; that is, this amount is in the railroad treasuries and has no claim on the operating revenues. While the net capital per mile has increased during the past quarter century from $49,500 to $63,100, it has not increased in proportion to the total capitalization. The capitalization per mile of American railways is in general much less than it is in European countries.

General Principles of Organization. Organization consists of combining, co-ordinating and directing the efforts of a group or groups of individual human units for the accomplishment of a definite common purpose. It is essentially a psychological and sociological problem as related to industrial operations, for two factors, namely, the individual man and the group, enter the consideration, the behavior of these two factors being quite distinct in many respects. The purpose of organization is to define and establish the relations of the individual to others of his group and the relations of the group to other groups. The term organization implies the placing of certain persons in authority to see to it that these relationships when defined and established are recognized and allowed to govern by all concerned. Mr. M. L. Byers,* Chief Engineer of Maintenance of Way of the Missouri Pacific R. R., gives the following general rules for forming an organization:

> 1. Provide a supreme authority at all points where action must be taken. The absence of such authority leads to indecision, jealousy, mediocre methods brought about by compromise, and to general disorder. Divided authority means evasion of responsibility.
> 2. Carefully and fully outline the authority and responsibility of each person. Uncertain boundaries of authority lead to conflict and to lack of co-operation.
> 3. Make the duties of the various positions conform to the capabilities of those occupying them. Natural abilities as well as technical training should be placed so as to serve to best advantage.
> 4. Avoid as far as possible making any person subordinate to two or more other persons, especially in regard to matters at all closely related. Unless this is done, friction and ill-feeling with accompanying poor performance may result.
> 5. Place the disciplinary authority in the same hands as the responsibility.
> 6. So distribute the burden of administration as to avoid unequal loading of the different officers. This course avoids overloading or underloading any one department, allays ill-feeling and makes possible a comparison of results accomplished.
> 7. There should be no positions which do not admit of ready promotion therefrom; otherwise, a powerful stimulus to effort is lost.

Much has been written in recent years concerning scientific management and scientific organization, but a further discussion of the subject is not called for in this connection.

Organization of Railway Officers. Although the details of organization vary with different railroads, there are certain fairly well-defined groups of operating officers that are recognized on almost all roads. These usually include the Executive, Legal, Accounting, Traffic, Operating or Transportation, Purchasing, Engineering and Mechanical departments. The President, who is elected by the Board of Directors as has been stated, has general charge of the entire road, and together with the vice-presidents, secretary, treasurer and their assistants, make up the first group, and the others are sufficiently well defined by their names. In some cases where the president is only nominally in charge of the road, having other interests to which he devotes his attention, the chief operating officer is the general manager, although the latter title is sometimes given to the head of the transportation department. The more detailed organization may be represented as in the following outline, which represents something of an average organization from a comparison of a number of typical American railroads.

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* "Economics of Railway Operation," p. 2.

EXECUTIVE
  President
  Vice-presidents
  Secretary
  Treasurer

LEGAL DEPARTMENT
  General counsel and assistants
  General solicitor and assistants
  General attorney and assistants

ACCOUNTING AND FINANCE DEPARTMENT
  Treasurer
  Comptroller and assistants
  Auditor and assistants
  Ticket auditor
  Freight auditor
  General accountant
  Paymaster and assistants

PURCHASING DEPARTMENT
  Purchasing agent and assistants
  General store keepers
    District storekeepers

Traffic Department
- Passenger traffic manager
  - General passenger agents
- General freight manager
  - General freight agents

Operating Department
- General manager and assistants, or
- General superintendent and assistants
  - Division superintendents
  - Train masters
  - Superintendent of car service
  - Superintendent of terminals
  - Superintendent of telegraph
  - Chief claim agent
  - General baggage agent
  - Superintendent of mail traffic
  - Chief dispatchers

Engineering Department
- Chief engineer
  - Assistant chief engineer in charge of design
  - Engineer of maintenance of way
    - Division engineers and assistants
  - Supt. or engineer of bridges and buildings
  - Bridge supervisors
  - Foremen of water service
  - Locating engineer
  - Assistant engineers
  - Resident engineers
  - Signal engineer

Mechanical Department
- Superintendent of motive power, or
- General mechanical superintendent
  - Mechanical engineer
  - Electrical engineer
  - Master mechanics

Frequently one of the vice-presidents whose training and experience have been in the particular line involved is in direct charge of one or more of the above departments.

Types of Organization. So far as most of railway operations are concerned, it may be said that there are two fairly distinct types of organization in vogue in the United States, namely, the Divisional and the Departmental.

In the divisional system, each division is operated practically as an independent line, under the direction of the division superintendent, who has charge of operation or conducting transportation, train service, maintenance of way and maintenance of equipment on his division. Under the departmental system, all activities related to any one department center around one head official who has charge of those activities for the entire line. Thus in the divisional system, the division engineer reports to the division superintendent and only through him to the chief engineer; whereas, in the departmental system, the division engineer reports directly to the chief engineer and any business that the division superintendent may have with the division engineer must be conducted through the heads of their respective departments. It is claimed that under the divisional type of organization, responsibility is more centralized and a more satisfactory correlation of the work of the division is effected, while under the departmental type greater uniformity of practice over the entire line is secured. Fig. 4 shows the essential difference between the two types of organization. Of forty-two roads investigated by the Committee of the American Railway Engineering Association,* twenty-three, representing 56,000 miles of line, employ the divisional system, while nineteen representing 40,000 miles use the departmental.

The organization of engineering forces for location and for particular work will be considered in another place.

The Unit System of Organization. A scheme of railway organization, called the unit system, was devised by Mr. Charles DeLano Hine in 1908 with a view to applying it to the Harriman Lines, where it has been adopted to a certain extent, and appears to have many points of merit. The scheme is based essentially on the division as the unit, under the direction of the division superintendent with assistant superintendents in charge of special lines of work. The number of assistant division superintendents would vary from perhaps one on small divisions to twelve on large busy divisions, the normal number being about six. These assistant superintendents are to be appointed with a definite rank of seniority and authority. Under this scheme, the division engi-

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* Proc. Vol. II., p. 243.

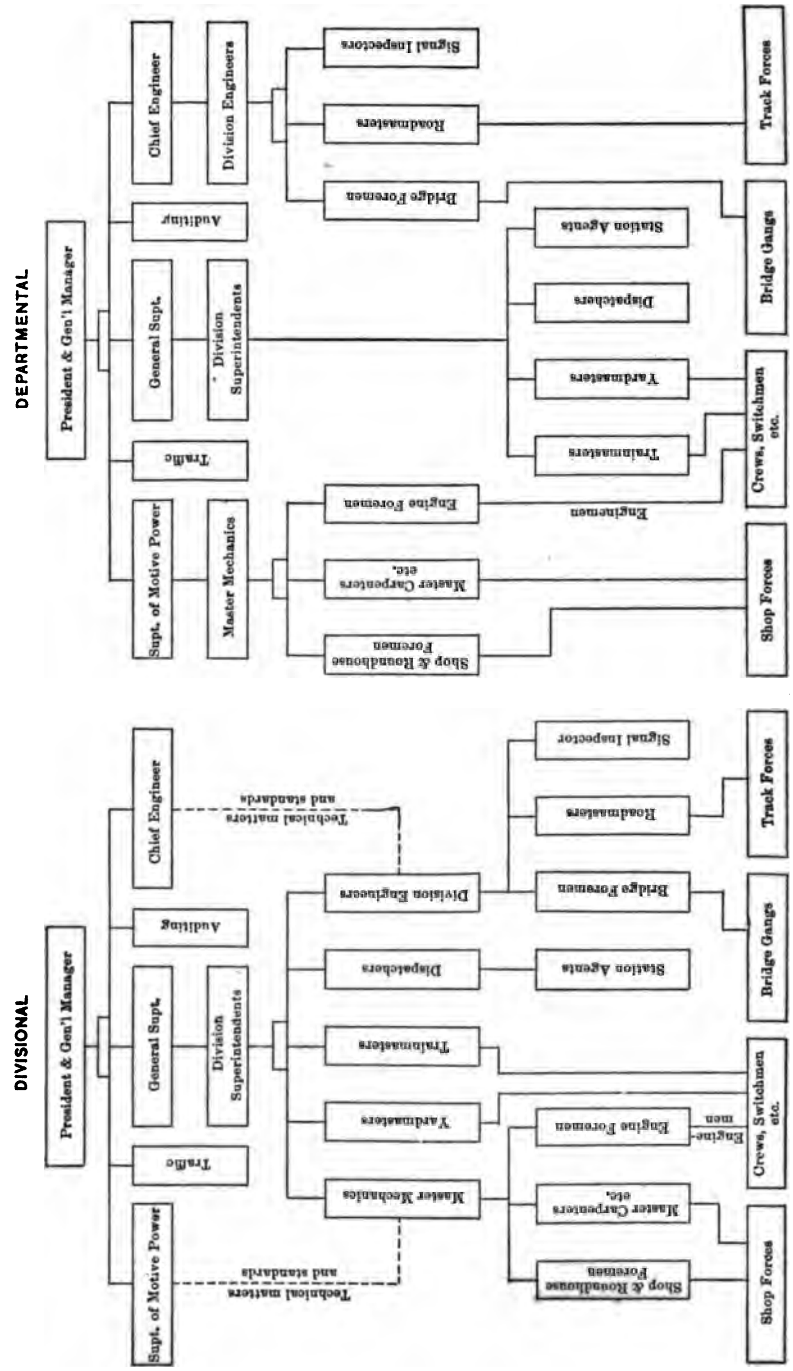

FIG. 4.—Divisional and Departmental Organisation.

neer, the master mechanic, the chief dispatcher, the purchasing agent, etc., still remain in charge of their respective branches of the service but with the title and authority of assistant superintendent. The advantages claimed for this scheme of organization are (1) that final authority in each instance issues from the one in the superintendent's office competent to speak on the question involved, instead of issuing from a chief clerk, (2) that it broadens the vision of each of these officers so that he has in mind every part of the division, and (3) that it removes jealousies and antagonism between departments.

Another essential feature of Mr. Hine's plan is the sharp distinction between " line " and " staff " functions. His pattern is the army organization in which a staff plans a campaign and line officers carry it into effect. The fundamental idea is that designing and originating projects requires maximum intellectual attention untrammeled by the worries of routine administration. On the other hand, the line officer, the man in the field on the job, is free from statistical or mathematical details and, being constantly in charge of directing the work of a force of men, is better able to perform such duties. However, it may be stated in passing, that a man for a responsible position either as a staff officer or line officer should have served a good apprenticeship in both, so that, in whichever one he may be employed, he will not disparage the other.

Like the railways themselves, the organization of American railroads has grown largely without design or direction and is cumbersome and antiquated in many respects. Some persons have made extravagant claims as to what savings might be effected by improved organization. As a matter of fact, it is doubtful if any other industry in the United States of similar magnitude is managed with equal efficiency. However, it is doubtless true that losses do occur under the existing organizations and that economies might be accomplished by the introduction of improved methods, and it is probable that the chief advance of the railroads will be made along this line in the future rather than in connection with purely technical matters.

CHAPTER III

GOVERNMENTAL CONTROL OF RAILWAYS

Introduction. As has been stated in another place, the railways of the United States grew without plan or system and without anyone connected with them having a definite conception of what the ultimate condition of affairs would be. Before the period of consolidation and monopoly forming, when the railroads were competing one against the other, when the railroads were chiefly local enterprises, no need of general control was felt. At the close of the last century, however, there came a period of organization of business on a large scale and of trust formation. Small industries were united under one holding company in order to promote economic betterment. Railroads were likewise collected into large systems. There are at present 2165 railroads in the United States doing interstate business, but they all are operated under only about fifty-seven different systems, according to the report of the Interstate Commerce Commission. As the railroad systems organized and became powerful, it was soon recognized that some sort of control would be necessary to bring about proper and just traffic conditions. Certain abuses had grown up, the chief of which will be mentioned incidentally in this chapter, and the Federal Government has undertaken to control the railroads that do an interstate business and the various states have enacted legislation looking to the regulation of intrastate commerce.

Authority for Federal Control. The constitutional authority under which the Federal Congress acted in passing the Interstate Commerce Act as well as all other laws pertaining to the regulation of railroads lies in the clause of the Constitution which states that Congress shall have power to regulate commerce between states. The clause was inserted without any idea of its being applied to the railroad situation of to-day, but rather with a view to giving that body power to regulate the collection of imports and exports on the merchandising between states. It grew out of the jealousies of the smaller states, who were fearful lest the stronger ones should take an unjust advantage in this respect. Had the present conditions been foreseen, other provisions might have been made that would have served the needs better. However, on this slender thread of constitutional authority are hung the many laws and the elaborate decisions relating to interstate commerce. In addition to this source of authority, Congress as a governing body had authority from common law to deal with railroads as common carriers (that they are such was shown in the first chapter), and to regulate their operations to the extent that common carriers had in times past been controlled by legislation. Moreover, the fact that the Federal Government had given subsidies in the form of land grants and money bonuses furnishes an additional control over these roads, for the legislative enactments that made these grants invariably provided for some sort of governmental control. It is perhaps unfortunate that the Federal Government has not been given authority for complete control of all business on interstate railroads regardless of whether the business were interstate or intrastate, because the present divided control has led to endless confusion and waste.

Eminent Domain. The right of eminent domain is the right belonging to a sovereign power to control and regulate rights of a public nature and to appropriate and control private property for the public benefit, as the public safety, necessity, convenience, or welfare may demand. This right was formerly one pertaining to majesty and it naturally descended to the sovereign power of a democracy, viz., the people themselves. The state has the right to bestow this attribute or certain phases of it upon any person whom it may choose, but the right cannot be exercised unless it has been specifically bestowed. It is conferred upon railroads and certain other public service corporations on the theory that such corporations are benefits to the public. The object of allowing railroads to exercise the right of eminent domain, which usually arises in taking private land for right of way, is to prevent an individual from hindering the progress of such an undertaking and the consequent common benefits resulting therefrom by refusing to sell the land required for its construction.

The method of procedure is about as follows in obtaining land by this process: The railroad deposits a bond for a specified amount, adequate to cover the probable cost, with a court of competent jurisdiction and then enters upon the land. The value of the land is then assessed by a jury or board of appraisers and the value of the land plus all damages sustained by the owner are paid him directly by the railroad, or by the court out of the bond. Whatever remains of the bond is returned to the railroad company. The whole procedure is commonly called condemnation proceedings.

In this manner, a railroad can obtain land for right of way for new construction, for buildings and yards, for additional tracks and for other improvements. It has been held also that a railroad can condemn and take land for a cut-off or other realignment, even though the railroad has already obtained one right of way for the same line.

Common Carriers. Due to the public nature of their business, railroads are called common carriers, a term that arose in early common law applying to stagecoaches, draymen, etc. A common carrier is one who undertakes to carry goods or persons for hire for whomsoever may employ him. The term embraces draymen, expressmen, railroads, bargemen, steamboat companies, pipe lines, etc. Common carriers are distinguished from private carriers by their manner of employment and by their responsibilities. If **A** employs his neighbor, **B**, to haul produce for him, **B** is a private carrier and is responsible to **A** only for gross neglect. If a person, however, does general carrying business for the public, he becomes a common carrier and must exercise extraordinary diligence in delivering safely goods intrusted to him. The liability of a common carrier begins when goods are delivered to him or to his agent at the usual place of business and are accepted by the carrier for transportation, and continues until they are technically delivered to the consignee. Common carriers are not obliged to accept for transportation goods of a nature other than what they profess to carry, nor to undertake to carry goods by other than the customary means and route. They are not compelled to undertake to carry goods of a dangerous nature, nor goods unfit for shipment, and they may require transportation charges to be paid in advance. On the other hand, common carriers are bound to provide facilities adequate for transportation of all freight and passengers which may be reasonably expected, but they are not bound to provide for extraordinary congestion of traffic.

Common carriers are held to be the insurers of goods against all losses except (1) those caused by agencies beyond human control, such as tempest, lightning, earthquake, flood, etc., (2) those caused by an act of a public enemy including foreign foes, rebels, rioters, mobs, etc., (3) those resulting from the fault of the shipper, (4) loss inherent in the articles shipped, as extra perishable commodities, and (5) losses resulting from an act of public authority, such as confiscating a cargo for the public good.

The duties and obligations above mentioned as being incumbent upon a carrier apply also to goods offered the carrier by a connecting carrier. One carrier whose lines connect with those of another cannot refuse to deliver goods to, nor receive goods from, the connecting carrier's lines. When several connecting carriers undertake to transport merchandise, the line upon which the loss occurs sustains the loss, although, by a special provision of the Interstate Commerce Act, the road receiving the goods is held liable to the shipper for such loss. A common carrier has a lien on goods transported by him to cover the actual charges of transportation, but this right does not extend to incidental charges such as demurrage.

Railway Nationalization. Owing to the close relationship existing between the railways and society, some have advocated the ownership and operation of railways by the government. The railways of Germany, Russia, France and most other Continental countries as well as those of Australia and some other English colonies are government owned, representing about 30 per cent of the railway mileage of the world. In Mexico, a unique scheme has been adopted which seems to offer many of the advantages while avoiding most of the dangers of government ownership. There the national government owns a controlling interest in all the roads and hence can dictate their general policies, but the operation of the lines is under private control as it is in the United States. The arguments commonly advanced in favor of government ownership are:

1. It would obviate losses resulting from competition.

2. A comprehensive system of trunk lines and feeders could be developed which would be an economy in many respects.

3. Possible uses for public purposes could be more readily effected.

4. There would be less labor disturbance.

Some of the arguments against government ownership are:

1. Inability of a government bureau or organization to handle the railways properly.

2. Inevitable political entanglements and abuses would result.

3. Cumbersome methods employed would militate against a service responsive to the public needs.

In the history of railroads in the United States, several lines were built by the separate states, but they were found to be unsatisfactory and gradually passed into private ownership.

Interstate Commerce Act. Under the authority conferred by the Constitution to regulate commerce between states, an act providing such regulation was passed by Congress in 1887 and has been amended in various important respects since that time, there having been about nine such modifications in all. This act as amended contemplates the control of numerous corporations doing business between states, its provisions applying "to any person or persons engaged in the transportation of oil or other commodity, except water and natural or artificial gas, by means of pipe lines, or partly by pipe lines and partly by railroad, or partly by pipe line and partly by water, and to telephone, telegraph, and cable companies (whether wire or wireless) engaged in sending messages from one State, Territory, or District of the United States, to any other State, Territory, or District of the United States, or to any foreign country, who shall be considered and held to be common carriers within the meaning and purpose of this Act, and to any common carrier or carriers engaged in the transportation of passengers or property wholly by railroad (or partly by railroad and partly by water when both are used under a common control, management, or arrangement for continuous carriage or shipment), from one State or Territory of the United States or the District of Columbia, or from one place in a Territory to another place in the same Territory, or from any place in the United States to another place in an adjacent foreign country, or from any place in the United States through a foreign country to any other place in the

United States, and also to the transportation in like manner of property shipped from any place in the United States to a foreign country and carried from such place to a port of trans-shipment, or shipped from a foreign country to any place in the United States and carried to such a place from a port of entry either in the United States or an adjacent foreign country: *Provided, however,* That the provisions of this Act shall not apply to the transportation of passengers or property, or to the receiving, delivering, storage, or handling of property wholly within one State and not shipped to or from a foreign country or to any State or Territory as aforesaid, nor shall they apply to the transmission of messages by telephone, telegraph, or cable wholly within one State and not transmitted to or from a foreign country from or to any State or Territory as aforesaid.

"The term 'common carrier' as used in this Act shall include express companies and sleeping-car companies. The term 'railroad' as used in this Act shall include all bridges and ferries used or operated in connection with any railroad, and also all the road in use by any corporation operating a railroad, whether owned or operated under a contract, agreement, or lease, and shall also include all switches, spurs, tracks, and terminal facilities of every kind used or necessary in the transportation of the persons or property designated herein, and also all freight depots, yards, and grounds used or necessary in the transportation or delivery of any of said property; and the term 'transportation' shall include cars and other vehicles and all instrumentalities and facilities of shipment or carriage, irrespective of ownership or of any contract express or implied, for the use thereof and all services in connection with receipt, delivery, elevation, and transfer in transit, ventilation, refrigeration or icing, storage, and handling of property transported; and it shall be the duty of every carrier subject to the provisions of this Act to provide and furnish such transportation upon reasonable request therefor, and to establish through routes and just and reasonable rates applicable thereto; and to provide reasonable facilities for operating such through routes and to make reasonable rules and regulations with respect to the exchange, interchange, and return of cars used therein, and for the operation of such through routes, and for providing reasonable compensation to those entitled thereto."

In order to carry this act into effect properly, one of its provisions established the Interstate Commerce Commission, whose functions will now be briefly outlined.

Interstate Commerce Commission. The body established for the purpose of construing and applying the provisions of the Interstate Commerce Act, known as the Interstate Commerce Commission, consists of seven members appointed for seven years, one Commissioner's term expiring each year, at a salary of $10,000 per annum. No person officially connected with any common carrier or holding stocks or bonds of one is eligible to be appointed on the Commission. The Commission has its principal offices at Washington, but whenever the convenience of the public or of the parties involved may be promoted, the Commission may hold special sessions anywhere in the United States. It may, by one or more of its Commissioners, prosecute any inquiry necessary to its duties in any part of the United States. It is required to submit an annual report of its findings, which is published and made available to the public. The following are some of the more important powers conferred upon the Commission:

1. To inquire into the management of the business of carriers and to obtain from such carriers full information pertaining thereto, and to require annual reports of all carriers subject to the Act.

2. To subpœna witnesses and to require documentary evidence, such as books, tariffs, contracts, etc., to be submitted.

3. To hear complaints by any person, firm or association, or any common carrier, concerning anything done or omitted to be done by any common carrier.

4. To make investigations of its own initiative of the business of common carriers as affecting the public.

5. To prescribe "just and reasonable" rates and classifications and "just and reasonable" practices.

6. To investigate new schedules, classifications and practices (all new schedules and classifications are required to be filed with the Commission thirty days before going into effect), and to determine the propriety of such schedules, classifications and practices, and to suspend such new schedules if deemed proper. The burden of proof of the reasonableness of any schedule is on the carrier involved.

7. To establish through routes and joint rates and classifications, within certain limitations.

8. To award damages to a complainant against a carrier if, after a hearing, such damages are found to exist.

9. To prescribe forms of accounting for common carriers subject to this Act.

10. To determine the value of all property of all carriers subject to this Act, and to employ experts for this purpose. (See Chap. IV.)

Many minor provisions and implied powers are conferred by the Act which need not be mentioned in this connection.

Other Provisions of the Act. The Interstate Commerce Act as originally enacted and later amended includes many provisions affecting carriers and interstate commerce other than that of creating and defining the powers of the Interstate Commerce Commission. Among these the following regulations may be mentioned as bearing more directly on the subject at hand:

1. The giving of free passes and free transportation is prohibited except to employees and their families and to a few other classes of persons. Interchange of passes between railroads is allowed.

2. Railroads cannot transport commodities manufactured by themselves, which means that they cannot own mines, manufactures, etc. Timber is excepted. This is known as the "Commodities Clause."

3. Common carriers must construct switch connections to any other carrier's lines, or to a private track, whenever there is sufficient business to justify the same.

4. Unjust discrimination in rates between shippers is forbidden. This applies especially to large and small shippers. Rebates and similar practices are forbidden.

5. Unreasonable preference or advantage may not be given to one person or locality that is not accorded to all that are similarly situated.

6. In general, special or low long-haul rates are forbidden.

7. Pooling of freight and the consequent division of earnings are forbidden.

8. Railroads cannot own competing water carriers (Amendment 1912). The facts in this connection are to be determined by the Interstate Commerce Commission.

9. Schedules giving all information concerning rates and fares must be posted and kept open for public examination and must be filed with the Interstate Commerce Commission thirty days before taking effect.

10. Joint schedules must specify the carriers participating.

11. Persons claiming damage may elect whether to bring complaint before the Commission or before a Federal Court.

12. The carrier receiving goods for transportation is liable to the shipper for all loss or damage during shipment.

13. Each carrier subject to the Act is required to designate an agent in Washington upon whom service of notices and processes may be made on behalf of the carrier.

14. Penalties are provided for failure to comply with the provisions of the Act.

The *Elkins Act* passed in 1906 makes a railroad as well as the officers responsible for any misdemeanors committed by the officers. It also makes it a misdemeanor for any person to solicit or receive a rebate from a railroad company as well as for the railroad company to give rebates. The *Expediting Act*, passed in 1910, provides that any case in which the United States is the complainant may, by proper certification by the Attorney General, be given precedence in suits in equity in a Federal Circuit Court, so that such cases may be tried as quickly as practicable.

Other provisions of the Interstate Commerce Act need not be mentioned here, but for a further study a copy of the act itself should be obtained.

State Regulation. States obtain authority to exercise control over the railways within their boundaries from the conditions of granting the charters, because of grants and bonuses given in some instances, and from the common law right to control common carriers. Naturally, state control is limited to the borders of the state and is subordinate to Federal control. Certain limitations to state control were fixed by the decisions in the Minnesota Rate Cases, which are discussed later in this chapter. All of the states have enacted laws seeking to regulate railroad activities, and all but five, Delaware, Utah, West Virginia and Wyoming, have public service commissions created for the purpose of such regulation. The special enactments of each individual state involved in any project should be closely scanned for any provisions that might affect railroad operation in that state. Obviously only a very brief résumé of the various state enactments can be given here, covering only a few of the most general and most important provisions.

The Controlling Body. In most of the states, the controlling body is called the Railroad Commission, in others, the Public Utilities or Public Service Commission, in others, the Railroad and Warehouse Commission, and in one the State Corporation Commission. The body usually consists of from three to five members appointed by the governor of the state. In very few states is there any statute prescribing the qualifications of the commissioners. Maine, Michigan, Nevada, and Ohio laws state that one commissioner shall be a lawyer and the other two railroad men. The Maine law requires that one shall be a lawyer, one a civil engineer and one a man experienced in the management and operation of railroads. In many states the law prohibits members of the commission from having any connection with any carrier.

The jurisdiction of the commission usually extends to all transportation and express companies, sleeping-car and other car companies, and to telephone and telegraph companies. The commissioners are commonly empowered to regulate rates, correct abuses of management and in general exercise a regulative influence over the operation of such companies. To this end, they are empowered to examine the books of any company and to secure information from its officials under oath. In several states the commissioners may mediate in controversies affecting public utilities.

Fixing Rates. The laws of practically all states having a commission follow the Federal statute in stating that rates and tariffs shall be just and reasonable, and provide for penalties in the case of extortion or unjust discrimination. The commissions are generally empowered to fix rates, although the United States Supreme Court has decided (Minnesota Rate Cases) that rates fixed by states shall not be confiscatory. Many states have definitely established rates which are tabulated in the statute books, while others have laid down general rules for making up through rates, etc. The New York law states, "In determining the rates of common carriers, railroad and street railroad corporations, commission shall give due regard, among other things, to a reasonable average return upon the value of the property actually used in the public service and to the necessity of making reservation out of income for surplus and contingencies." (Laws, 1910, Ch. 480.) The Massachusetts law is similar in providing, "Railroad commission in fixing or changing rates of carriers shall give due regard among other things to a reasonable return upon the value of the carrier's property." (Acts, 1911, Ch. 755.) Several other states have similar provisions.

In order to ascertain the value of the carrier's property, the following states have made provision for making a valuation of the railroad properties within their jurisdiction: Arizona, Arkansas, California, Florida, Georgia, Kansas, Maryland, Massachusetts, Michigan, Minnesota, Nebraska, New Jersey, Ohio, Oklahoma, Oregon, Pennsylvania, S. Dakota, Texas, Washington, Wisconsin and perhaps a few others. Very few of the statutes have attempted to prescribe a method of making such a valuation, although a few have done so. For example, the Kansas statute reads, "Commission shall ascertain as early as practicable the amount of money expended in construction and equipment per mile of every railway in the State, the money expended to procure right of way, and the amount of money it would require to reconstruct the roadbed, track, depots and transportation facilities and to replace all the physical properties belonging to the railroad." (Stats., 1909, Sec. 7217.)

Practically all of the states, following the provision of the Interstate Commerce Act, require that no change be made in tariffs or other charges without such changes being published for a period varying from ten to thirty days before they take effect, and that the proposed schedules be filed with the commission for a like period. They also provide that all tariff rates shall be open to inspection by the public and that they shall be printed distinctly so that they may be easily read and understood.

Unjust Discrimination and Rebating. In order to encourage large shippers to use their lines, the railroads made a practice of refunding a portion of the freight charges to such shippers and in other ways discriminating in their favor. Such refunds are called rebates. In most states the statutes expressly forbid charging a greater amount to one person than to another for a like and contemporaneous service. For example, the Wisconsin statute reads, "If any railroad or any officer or agent thereof shall directly or indirectly by any special rate, rebate, drawback or by means of false billing, false classification, false weighing or any other device whatsoever charge, demand, collect or receive from any person, firm or corporation a greater or less compensation for any service rendered by it for transportation of persons or property or for any service in connection therewith than that prescribed in the published tariffs then in force or established by law or than it charges, demands, collects, or receives from any other person, firm or corporation for a like and contemporaneous service, such railroad shall be deemed guilty of unjust discrimination, which is prohibited and declared unlawful, and upon conviction thereof shall forfeit and pay into the state treasury not less than $100 nor more than $10,000 for each offense; and any agent or officer so offending shall be considered guilty of a misdemeanor and upon conviction thereof shall be punished by a fine of not less than $50 nor more than $100 for each offense."

Size of Shipment. In order to prevent a certain form of discrimination some of the states have specific laws prohibiting carriers from charging lower rates for large shipments than for small. The Iowa statute in this regard is typical and reads, "No common carrier shall charge, collect, demand or receive more for transporting a car of freight than it at the same time charges, collects, demands or receives per car for several cars of like class of freight over the same railway, for the same distance and in the same direction; nor charge, collect, demand or receive more for transporting 100 lbs. of freight than it charges, collects, demands or receives for several hundred pounds of freight, under a ton, of a like class, over the same railway, for the same distance, in the same direction." (Code, 1897, Sec. 2146.)

Long and Short Haul Clauses. In order to meet water competition, railroads in certain instances made extremely low rates for long distance hauls and higher rates to intermediate points. For example, the rate from New York to Seattle had to meet the water rate, consequently the rate to such an inland city as Spokane was made equal to the rate to Seattle plus the back haul rate from Seattle to Spokane. To a certain extent, a higher rate per ton mile is justified for a short haul than for a longer one owing to the high proportion of the total cost of transportation involved in handling at the terminals. However, the "long and short haul" clause was intended to prevent a larger charge for a short distance than for a longer one when the short distance is comprehended in the longer one. Thirty-six of the states following the lead of the Federal Government, have enacted laws almost identical with Sec. 4 of the Interstate Commerce Act, which states, "That it shall be unlawful for any common carrier subject to the provisions of this Act to charge or receive any greater compensation in the aggregate for the transportation of passengers, or of like kind of property, for a shorter than for a longer distance over the same line or route in the same direction, the shorter being included in the longer distance, or to charge any greater compensation as a through route than the aggregate of the intermediate rates subject to the provisions of this Act." The Interstate Commerce Commission, however, may modify this provision to a certain extent if after investigation it should find such action justified. The statutes of Illinois and of several other states expressly provide, however, that "nothing herein contained shall be so construed as to prevent railroad corporations from issuing commutation, excursion or thousand-mile tickets, as the same are now issued by such corporations."

Adequate Service and Facilities. That common carriers shall provide adequate facilities for doing the business which they are supposed to do, is provided in most state legislation as well as in the Federal Act. The laws of Kansas are typical in this respect: "Every common carrier and public utility governed by the provisions of this Act shall be required to furnish reasonable, efficient and sufficient service, joint service and facilities for the use of any and all products or services rendered, furnished, supplied or produced by such public utility or common carrier." Also, "Every railway company, express company and telegraph company shall furnish adequate telephone connections between its offices, buildings and grounds and the public telephone exchanges operated in the towns where the same are located."

In regard to the character of maintenance, twenty-eight states have laws of which the Indiana law is typical: "Whenever Commission shall secure reliable information or complaint shall have been made, or, because of reports made by inspectors, shall have reason to believe that any carrier does not keep its road or equipment in proper condition and repair for the security of its employees or the public, or that any carrier does not maintain adequate and suitable depots, buildings, platforms, switches, and sidetracks for passengers and for the receiving, protecting, handling, forwarding, and delivery of all freight offered for shipment or received at said stations, or that there is a dangerous defect in connection with the operation of any railroad or any railroad bridge, culvert, curve, embankment, water tank, crane, frog, railroad or wagon road crossing, ties or tracks, motive power, stations, rolling stock, machinery or in any roadbed or ground used in connection with the operation of any railroad, or any dangerous neglect or fault in the construction, equipment or management of any railroad, Commission shall cause such investigation to be made as it may deem necessary, and when such investigation shall have been made, said Commission shall make a report to the manager or superintendent of the railroad company. In said report and recommendations, Commission shall make an accurate statement of the time such examination was made, of the exact location, character and extent of such defects or omissions, if any such shall have been found, and shall also recommend such reasonable changes and improvements, additions, buildings and accommodations, as are, in the opinion of the Commission, necessary to remedy such faults, neglects, requirements or defects. Such recommendations shall set out specifically a reasonable time within which such improvements, changes or additions shall be made by the railroad company. And if they are not so made within the said time specified, then Commission, if it deem it best to do so, may commence proceedings by mandamus or other remedy in some circuit or superior court having jurisdiction of the carrier to enforce compliance with its order. All courts shall give preference to such cases and determine the same speedily to the end that public interest may not suffer." (Acts, 1911, Ch. 76.)

Safety of Operation. Perhaps the most feasible field for state legislation in controlling railroads is in matters pertaining to safety of operation, particularly in matters of a local nature. Some thirty or more states have passed legal enactments affecting various phases of operation relating to safety. The acts usually provide (1) that in the case of new construction, the roadway and other facilities be certified as safe by the commission, (2) that facilities may be inspected at any time by the commission and repairs ordered, (3) that in case of accidents resulting in death or serious injury, the commission is authorized to investigate the circumstances and that the officers are required to report all such accidents to the commission. The Massachusetts law reads as follows: " Commission shall have the general supervision of all railroads and railways, and shall examine the same, and the Commission shall keep itself informed as to the condition of railroads and railways and the manner in which they are operated with reference to the security and accommodation of the public, and as to the compliance of the several railroad corporations and street railway companies with their charters and the laws of the state. Commission may from time to time require railroad corporations and street railway companies to install and maintain at such places upon the railroad or street railway premises as it shall designate such block or other signals or devices as it shall approve for the purpose of safeguarding public travel." (Act 1906, Ch. 463.)

Granting of Franchises. At least twelve states have a legal requirement that public utilities must show a social need of their existence before a franchise or charter may be granted. The Kansas law is representative of these provisions: " No common carrier or public utility shall transact business in the state until it shall have obtained a certificate from the Commission that public convenience will be promoted by the transaction of said business and permitting said applicants to transact the business of a common carrier of public utility. This section shall not apply to a common carrier or public utility governed by the provisions of this act now transacting business in the state." (Laws 1911.)

Such laws are intended to prevent the unjustifiable enterprises in railroad building which may be the result of wildcatting operations of unscrupulous promoters or the unwise application of community effort. Most of the states having a railroad commission, confer upon municipalities the right to control street railways within the municipal limits.

Issue of Stocks and Bonds. The right to issue stocks and bonds by creating a lien upon corporate property is specifically declared by some states to be a special privilege and subject to the control of the public service commission. The law of Kansas may be quoted to illustrate: "A public utility or common carrier may issue stocks, certificates, bonds, notes or other evidences of indebtedness, payable at periods of more than twelve months after the date thereof, when necessary for the acquisition of property, for the purpose of carrying out its corporate powers, the construction, completion, extension, improvement or maintenance of its service, or for the discharge or lawful funding of its obligations, or for such other purposes as may be authorized by law; provided, and not otherwise, that there shall have been secured from the Commission a certificate stating the amount, character, purposes and terms on which such stocks, certificates, bonds, notes or other evidences of indebtedness are proposed to be issued, as set out in the application for such certificate, and the statements contained in such application have been ascertained to be true." (Laws, 1911.) Arizona, California, Kansas, Ohio and Wisconsin also have provision for controlling the issuing of dividends.

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Minnesota Rate Cases. Because of their far-reaching influence and the length of time they were in court, certain rate cases, known as the Minnesota Rate Cases, require brief mention in this connection. In 1906 the Railroad and Warehouse Commission of Minnesota issued certain orders declaring that existing rates in instances cited were unreasonable, and establishing a new schedule of maximum rates. The Northern Pacific, the Great Northern and the Minneapolis and St. Louis railways, doing chiefly an interstate business, brought suit to restrain the enforcement of these orders and of two acts of the legislature prescribing maximum charges for the transportation of freight and passengers. The complainants assailed the acts and orders on the grounds that (1) they amounted to an unconstitutional interference with interstate commerce, (2) they were confiscatory and (3) the penalties imposed for their violation were so severe as to result in a denial of the equal protection of the laws and a deprivation of property without a due process of law. The circuit court referred the suits to a special master in chancery who took the evidence and made an elaborate report sustaining the complainants' contentions, with one minor exception, and in this report the court concurred. The attorney general of the state and the commission appealed the case to the United States

Supreme court. Without quoting at length, the decision of the Supreme Court included the following points:

1. The Constitution gives Congress adequate authority to secure the freedom of interstate commerce from state control and to provide the necessary regulation.

2. The state has control over commerce that is strictly intrastate.

3. Where matters falling within the state's power are also by reason of their relation to interstate commerce within the reach of Federal jurisdiction, Congress must judge of the necessity of Federal action, and until Congress acts the state may act.

4. The Court found that the acts in question did not interfere with the Federal regulation of interstate commerce.

5. The Court decided that in general the rates were not confiscatory, but stated that private property " rests secure under the constitutional protection which extends . . . to the right to receive just compensation for services given the public." In other words, the Supreme Court affirmed the right of the state to fix rates, but such rates must allow to vested private property just compensation for services rendered to the public.

CHAPTER IV

VALUATION OF RAILWAYS

Introduction. In recent years, so many questions involving the valuation of railway property have arisen that a brief discussion of this subject appears to be necessary in connection with the economics of railway location. Much information of direct use in considering proposed railways, and especially in considering matters pertaining to the relocation and rearrangement of existing lines, may be obtained from a study of the history and valuation of existing roads. The relation of a proposed road to those already in operation, a matter of very great importance in the present status of railroad building, can be best understood if a more or less intimate knowledge of the valuation of existing roads is first obtained. Moreover, the reasons why some roads have prospered while others have failed are best comprehended from a study of the elements of value, and particularly from an understanding of those values commonly known as intangible values, such as strategic location, franchises, a going business, etc. With a view to a systematized investigation of the status of the railroads, particularly in regard to their financial condition and the rate situation, the Federal Government as well as many of the states has undertaken a careful examination of the valuation of American railways. For these reasons, a brief outline of the subject is attempted in the present chapter.

Meaning of Valuation. Before proceeding to discuss the purposes and methods of making valuation of railroad properties, it will be well to pause to determine, if possible, what is meant by valuation. To state that " valuation means to determine the value of " is only changing the form of the question, for the word value is one of many and varied applications. A casual study of definitions given in the dictionaries shows that different authors define the word from different points of view. One such definition which seems most nearly to meet the general requirements of the word is, " The property or aggregate of properties of a thing by which it is rendered useful or desirable, or the degree of such property or sum of properties." In trade, value means "the efficiency in exchange." A railroad, however, has very little exchange value if it cannot be used for the purpose for which it was constructed, that is, the scrap value would be small in comparison with the cost of production. If the value of a public utility is to be measured by what it will bring on the market, then evidently, the value of such utility will be dependent upon what it will earn rather than upon what it cost to produce it. The conclusion is apparent, therefore, that the value of a property will depend largely upon the purpose for which the valuation is to be made. Moreover, it is manifest that certain properties which are physically identical, but due to different earning power, may have very different values so far as exchange is concerned. Thus, a utility which is already producing an income, or in technical terms, is a going concern, will have a greater value than one like it but without a business established.

From the above, it appears that value is not an elemental term, but is itself composed of certain elements or factors. An understanding of these factors is the first essential in considering matters pertaining to valuation. The two chief elements are:

1. *Physical value*, or the value of the physical property, dependent upon cost of production and all non-physical property connected with its installation.

2. *Intangible value*, or that portion of the value which depends upon circumstances, including development expenses, franchise value, going value and good-will value, and value of strategic right of way.

To determine the amount of these two elements is a matter of much difficulty and one upon which opinion differs widely. At another place in this chapter, a brief discussion of the underlying principles and the methods employed will be given, although any attempt at complete treatment is impracticable.

Purposes of Valuation. The most frequent need of valuation of railroad property rises from one or more of the following requirements:

1. Taxation.
2. Purchase.
3. Capitalization and issuance of bonds.

4. Establishment of a uniform system of accounting.
5. Rate making.
6. In ascertaining a proper depreciation reserve.
7. In ascertaining a trustworthy estimate of the relation between present worth of railway property and the original cost.

The results of a valuation will depend largely upon which one of the above purposes was in mind when the valuation was made. The following extract from the Proceedings of the National Association of Railway Commissioners, 1911, will help to make this matter clear:

"How, for example, can a state commission recognize four different kinds of value and make one valuation for municipal purchase, another for taxation, another for rate making and another for capitalization? To do so seems at first thought inconsistent. On the other hand, a little consideration will show that value is meaningless unless made with reference to some particular object. To be sure, it may happen that fair value for one purpose is fair value for another, but in order to determine what is fair value for any specific purpose it is necessary to think it out with reference to this purpose only, and when we discuss the theory and elements of valuation, it seems necessary that we have in mind a specific purpose that the valuation is to serve."

Mr. George F. Swain in his report on the valuation of the N. Y., N. H. & H. R. R. states a similar proposition: "The principle upon which such valuation should be made will differ according to which of the above purposes is in view. It should be remarked, however, that physical valuation alone, by any method, is not a proper scientific basis for some of the above purposes, or perhaps for any of them. In the case of Smyth vs. Ames, the Supreme Court of the United States declared that the physical valuation was only one of a number of elements to be taken into account in determining reasonable rates, and the same would hold true, in greater or less degree, for valuation for the other purposes named."

Methods of Making Valuation. Various methods for determining the value of a railway property have been proposed and used under different circumstances and at different times, among which may be mentioned the following principal ones:

1. *Nominal or Par Value of Stocks and Bonds.* This method from the manner of organizing and financing a railroad would give an incorrect measure of the true value of a railroad.

2. *Stock Market Valuation of Stocks and Bonds.* Since the brokers who determine the market price of railway stocks and bonds make it a business to deal in such securities and hence are experts in that line, the market value of stocks and bonds might be thought to represent the true value of the railroad property. Such, however, is not necessarily the case, owing to speculative influences at work in the control of market values. Such a value, on the other hand, does bear a certain relation to the earning capacity of the railroad.

3. *Capitalization of Net Earnings.* As an investment, a purchaser is chiefly concerned with the earning power of a railway and is usually willing to pay the amount on which the net earnings will pay a reasonable interest return. However, there are many elements of value, such as future possible development, that this method does not take into consideration.

4. *Physical Property plus Intangible Values.* This is the method commonly accepted as being the most reliable, although the methods of arriving at the correct results have been matters of much difference of opinion and widely discussed. In ascertaining the value of physical properties, three methods are most generally used, namely, (*a*) Original cost to date, (*b*) Cost of reproduction new, (*c*) Cost of reproduction less depreciation, or sometimes termed present value. These methods together with the determination of intangible values will constitute the subject matter of the remainder of this chapter.

Valuation for Taxation. Taxes are levied upon property in proportion to its value as nearly as such value can be determined. On farm land and buildings and similar property, the value is comparatively easily determined, but on railroads the problem is much more complicated. In regard to valuation for taxation, Mr. George F. Swain makes this statement: "Whether the physical valuation is a proper basis for taxation will depend on the tax laws. In some states the tax may be based to some extent, and possibly entirely, upon the physical value, exempting securities, franchises and value as a 'going' concern, while in other states the value may be based entirely upon net earnings, or upon the value of securities, perhaps with little or no reference to the physical property. If the physical valuation is made for taxation purposes, however, the present value of the property, taking account of depreciation, and probably with the addition of some amount to represent intangible values, would probably be considered a reasonable basis for such valuation, as far as it goes. Two properties, identical in all respects, one of which is capable, on account of its favorable location, of earning a large return, while the other, on account of its unfavorable location, is operated at a loss, would not, and should not fairly, be taxed equally. Taxation, it will probably be admitted, should recognize earning power as well as physical value."

In the case of the Bee Building Co.* the supreme court of Nebraska decided that under the laws of that state the railroads should be valued for taxation at the true value of their tangible and intangible property, including franchises, and taking into consideration the net earnings and the market value of the stocks and bonds. In other words, valuation for taxation should be the fair market value of the property as a going concern.

Valuation for Purchase. In ascertaining the value of a railroad property for purchase, it is quite generally agreed that the present or depreciated value of the physical property together with the franchise and going concern values constitutes the correct measure of its worth. This would probably be the case in a condemnation proceeding, but in a bargain and sale the earning capacity would have a greater influence doubtless on the sale price, hence, capitalized net earnings might be a governing factor. There have been several court decisions which tend to show that valuation for public or municipal purchase is very closely related to valuation for rate making, which is to be discussed later, therefore nothing further need be said concerning this matter here.

Valuation for Capitalization and Issuance of Bonds. The laws of the United States generally require that when stock certificates or bonds are issued, the amount issued shall bear some relation to the value of the property back of them, and the question arises as to what should be taken as the correct measure of this value. To quote again from Prof. Swain's able report, "Physical valuation does not, in general, appear to be a fully adequate basis for justifying capital, for such capital generally depends upon the historical development of the property, and some or much of it may represent property which has been abandoned, or machinery which has been made useless, by necessary relocations, or by improvements in mechanical processes. A railroad may, for instance, be built to-day and be operated by steam locomotives, and the capital may represent the exact sums spent for the property; but in the course of ten or twenty years it may become advisable to substitute electricity as the motive power, or the company may be forced to do so by legislation, rendering large expenditures necessary and the abandonment of its steam locomotives. Or the law may require electrification only in a metropolitan district, requiring large expenditure, but not allowing any material reduction in the service of the steam locomotives, because the steam runs would be the same as before, with a few miles cut off at either end. It would be reasonable that the additional expenditure in such cases should be capitalized (temporarily at least, subject to retirement out of earnings), yet the physical value of the resulting property might be no greater than before. . . . "

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* "Valuation of Public Service Corporation," by R. H. Whitten.

The many experiments in the development of a railroad, all of which are expensive and yet may not appear as property, the many expenses connected with improvements, such as elimination of grade crossings, double tracking, etc., which may be much greater than if these had been constructed when the road was first built, very likely do not appear in the property values as they exist after completion. If improvements are needed and can be justified economically, then the railroad should be allowed to obtain the necessary capital regardless of the past history.

Valuation to Facilitate Accounting. Valuation of physical properties and intangible assets may be undertaken in order to enable accounting books to be opened on an equitable basis. This situation arises more frequently in connection with municipal utilities than with railroads and therefore need not be considered here at length. Suffice it to say, that in such a valuation, the commercial or earning value of the various items of property would usually be considered the determining factor. However, in some cases, the present worth, or the cost of reproduction less depreciation, would be the more equitable valuation.

Valuation for Rate Making. In connection with railroads, rate making is perhaps the most important purpose for making a valuation owing to the fact that the courts have declared that a railroad is entitled to a reasonable return upon a fair value of the property invested and the consequent necessity of determining what constitutes such fair values. Obviously, in making such a valuation, the earning power should not be the determining factor, for rates and earnings are mutually interdependent and one should not be considered as a factor in determining the other. On the other hand, mere physical value is not the proper basis for fixing rates, for much of the capitalization may represent sums spent legitimately in experimentation which naturally do not appear in the physical properties. Moreover, the conditions of competition would not admit always of fixing rates by the value of the physical plant. Two railroads, for example, joining two termini, may represent very different expenditures in their construction, the one first built probably having occupied the best location and the second being forced to take a second choice with a resulting increased cost of construction, are obviously compelled by competition to charge the same rates. The Supreme Court of the United States in the Nebraska Rate Case in 1898 said, " The basis of all calculations as to reasonableness of rates to be charged by a corporation for maintaining a highway under legislative sanction must be the *fair value* of the property being used for the convenience of the public." What constitutes this *fair value* and how to determine the same is a question not easily answered and one on which expert opinion has been seriously divided. In the amendment to the Interstate Commerce Act of March, 1, 1913, which provided for the valuation of all interstate railroads, Congress directed the Interstate Commerce Commission to determine

1. The original cost to date.
2. The cost of reproduction new.
3. The cost of reproduction new, less depreciation.
4. Other elements of value (intangible values).

Each of the first three taken alone or coupled with the last item has been employed by engineers in valuation procedure, and Congress has left the question open as to which should be used in fixing rates by directing that all of these elements should be ascertained.

Original Cost. Some contend that the original cost of railroads should be taken as the fair value of their property and that they should be allowed a reasonable return on this cost only. The increased value of railroad property, however, is not of the nature of an unearned increment, since the railroads themselves are the chief factor in causing the increase in value, hence they should be given the benefit of the increase in the value of their property. Original cost to date is practically impossible to obtain, moreover, owing to the fact that the records of construction have seldom been retained, especially in the case of the earlier roads. (The Interstate Commerce Commission now requires such records to be kept permanently, and has issued a circular concerning the preservation of all records.) Since the original cost, or actual cost as it is sometimes called, includes both the cost of construction and the cost of additions and betterments over a long period of years, it is scarcely probable that such records, if available, should be complete. While the original cost method may yield a fair value for some utilities, owing to the reasons above stated and others, such as changes in unit prices, etc., it is not satisfactory for railroad valuation, especially as related to rate making.

Cost of Reproduction. For purposes of rate making on railroads, the cost of reproduction new under present conditions is doubtless the fairest method of arriving at the correct valuation and the courts have been inclined to so regard it. This method allows the companies to list their real estate, right of way, cost of construction, materials, etc., at present market prices, allowing for enhanced values instead of original cost. The public is really entitled to service at rates which would be required at present to produce such service, and should not be so much concerned with the good or bad bargains of the railroad in its period of construction and development. On the other hand, also, the company is entitled to receive a fair return on the investment which it or some other company would need to make in order to produce such service. In 1911, in deciding the Western Rate Advance Case, Commissioner Lane stated that perhaps the nearest approximation to fair value is that of bona-fide investment, considering as a part of the investment any shortage in return that may have occurred in the early years of the enterprise. The following is quoted from that decision:

"When asked by the Government why it has increased its charges, its (the Burlington Railroad) reply is that it has a right to do so because it is not now receiving a fair return upon the value of the property which it now uses; value being estimated cost of reproduction. This leads to a few questions: (1) What did the Burlington road cost to those who built it? (2) What is its present value? (3) Whence came this value? (4) Is such increase in value a basis for increase in rates?

"The comptroller of the company has given us the answer to the first question. He testified that the total investment in the property from the sale of stocks and bonds was $258,000,000. To the second question the company answers that its present value is $530,000,000. The difference between these figures represents (*a*) investment in the property made out of earnings; (*b*) increased right of way and terminals owned by the company. This is the answer to the third question."

After quoting certain court decisions bearing on the case, the Commissioner continues:

"Notwithstanding these decisions, it remains for the Supreme Court yet to decide that a public agency, such as a railroad created by public authority, vested with governmental authority, may continuously increase its rates in proportion to the increase in value, either (*a*) because of betterments which it has made out of income, or (*b*) because of growth of property in value due to the increase in value of the land which the company owns."

This reasoning holds good in part, but in many cases, the ownership of the railroad has little or no connection with original builders, for the present owners have for the most part purchased its properties at appreciated values. Obviously, if a certain piece of farm land is to be condemned and sold for public purposes, the fair value to be paid to the owner is not what he paid for it fifty years ago, much less what the original owner paid for it. Railroads belong to that class of semi-public corporations in which the public has much interest and an unquestioned right to control, but in which, at the same time, the owners' rights must be recognized and protected.

In determining the cost of reproduction new, the following items should be considered:

1. *Land Values.* Much right of way was donated to early railroads by the public and by private individuals, while in other cases the railroads were compelled to pay high prices for their land. Whether the value of adjacent land should be taken

as a basis of present value will have to be decided by exercise of judgment in each case. The value is sometimes taken as the price in recent sales, the assessed value for taxation, and sometimes fixed by estimate from local opinion. Experience shows that the sales or market value of land is approximately what the railroad paid for it in the case of land in cities of 100,000 population or more, whereas it represents not more than one-third the cost to the railroad in rural districts.

2. *Inventory of Measurable Items.* All items of property such as track materials, cuts and fills, bridges, culverts, buildings, fences, tunnels, water supplies, fuel stations, shops, grain elevators, warehouses, docks, telegraph lines, signals, interlockers, all rolling stock and floating equipment, must be inventoried and assigned values at unit prices.

3. *Overhead Costs.* These include (*a*) Engineering; (*b*) Contingencies, such as mistakes in estimating, damage claims, condemnation suits, floods, etc.; (*c*) General expenses, such as law, stationery, insurance, taxes, etc.

4. *Interest During Construction.*

5. *Working capital,* or the proper amount of funds necessary to begin business.

6. *Abandoned property* should doubtless be counted to some extent, the proper allowance being a much mooted question. Probably the reproduction cost at the date of abandonment is the most equitable value to use.

Cost of Reproduction New Less Depreciation. For certain purposes, the cost of reproduction new less depreciation represents a proper valuation of a railroad, but such a valuation should not be taken by itself as a basis for determining fair rates, unless, indeed, the depreciation is such as to affect the service. For public utilities that possess practically a monopoly in the territory controlled, when competitive conditions do not compel keeping the properties and service up to a certain standard, such a method may be acceptable. On the other hand, a railroad is forced by competition and by its charter obligations to keep its properties so that the service rendered may not suffer. Legal decisions as well as common practice indicate that all expenditures for renewals and repairs should be charged to operating expenses and not to capital; that is, normal deterioration or depreciation is not a diminishment of capital but is a part of operating expenses which is to be covered by the service rates. Funds must always be available to replace equipment and facilities as they become incapacitated, and as such funds are usually taken from the earnings, they cannot be considered as accruing to the benefit of the owners of the railroad. Mr. J. Wilgus makes the following pertinent suggestion: *

"In this connection, sight should not be lost of the impossibility of maintaining a railroad in a new condition. A well-maintained property in time reaches an average condition, say, 85 per cent or 90 per cent of new, which remains practically stationary. In such cases an appraisal with depreciation deducted will show a loss of value, though, as a matter of fact, the real worth will be greater. For instance, no one will deny that the Pennsylvania Railroad between Jersey City and Philadelphia is more valuable for the purpose for which it is used than a brand-new unseasoned parallel line having the same physical characteristics. Depreciation in cases like this is merely a measure of the cost of securing a seasoned railroad and may be considered as belonging in the same category as other legitimate overhead expenses."

Depreciation. Depreciation may be defined as that deterioration which is not made good by repairs and is more or less continuous throughout the life of the property. Mr. John W. Alvord defines depreciation as "the lessened value of any property, structure or machine, due either to its wear, loss of usefulness, growing lack of adaptation or approaching abandonment." From this it appears that depreciation may be either functional or physical. The following factors or elements may enter into depreciation, the first three being functional and the last two physical:

1. *Decrepitude,* or the gradual aging of the property. The rate of depreciation by decrepitude varies in different kinds of property. In simple steel or masonry structures it is small, while in structures of ornamental or less stable design it may be very rapid.

2. *Obsolescence,* or depreciation that results from advance in the art rendering the piece of property or apparatus obsolete or uneconomical to use. This is a very important item and will

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* Proc. Am. Soc. C.E., Vol. XL, p. 366.

be found frequently to limit the life of a structure which might have a much longer physical life.

3. *Inadequacy.* This includes the depreciation that results from the growth of business which renders certain equipment inadequate to the needs. Locomotives and cars become too small or light before they need to be replaced on account of wear. This is sometimes called *supersession,* since the equipment must be superseded by that of higher capacity.

4. *Wear and Tear.* This element of depreciation consists of the decrease in value due to normal wear. Obviously it varies greatly with the character of the property.

5. *Deferred Maintenance,* or *Depreciation Reserve.* This item embraces the depreciation due to postponing the making of needed repairs. The amount of the item is usually considered to be the sum necessary to put the equipment in good operating condition.

If depreciation is considered in determining a basis for fixing rates, the logical conclusion would be that functional depreciation only should be taken into account, for to a certain extent it represents a wastage of capital, while physical depreciation does not. Depreciation is in reality an operating expense and not a capital charge, and many eminent authorities, therefore, do not admit the logic of counting depreciation at all in connection with rate determination.

Various methods have been proposed and used in estimating depreciation, only three of which will be mentioned here, and that very briefly. A visual examination of the property in question is necessary and any rule of procedure must serve primarily as a guide to the judgment rather than as a definite determination. The measure of depreciation is the annual cost of maintaining the investment, and this cost is dependent upon the rate at which the latter is wasted away. The annual depreciation may be considered as the necessary annual installment of the annuity which will amount to the first cost of the property at the end of its useful life. It is obvious that this is equivalent to the annual wastage of the first cost, since the first cost and the cost of renewal are assumed equal. The three principal methods of estimating depreciation are:

1. The *Straight Line Method* is the simplest and most generally used. It assumes that the rate of depreciation is con-

stant; that is, if the scrap value or minimum maintenance condition of an item is V' at the end of N years and the initial value V, then the annual depreciation is $(V-V')/N$.

2. The *Sinking Fund Method* is widely advocated as a true estimate of depreciation, the amounts set aside to cover depreciation being considered as drawing compound interest. It provides a method of accumulating a sum at the end of a given period, equal to the assumed life of the property, that would amount to the difference between the original and scrap value. By principles of compound interest the fixed annual amount to be set aside is $(V-V')\frac{r}{(r+1)^N-1}$, r being the rate of interest.

For any given year these sums with their accumulated interest amount to essentially the same figure as that given by the next method.

3. The *Equal Annual Payment Method* was recommended by the special committee of the American Society of Civil Engineers and is based on the theory that the most equitable and practical procedure is one that causes the amount that the rate or tariff payer must contribute each year for interest on the remaining investment and for the depreciation charge to be constant. It is similar to the sinking fund method, but instead of making the payments for depreciation equal and assuming them to draw interest, the payments are made to include the interest, and hence constitute a sum equal to the required amount at the expiration of the life of the item. The depreciation allowance is not constant, but increases for each succeeding year. It amounts to $(V-V')\frac{r(1+r)^n}{[(1+r)^N-1]}$ for any nth year.

A further discussion concerning the much mooted question of depreciation is not warranted here.

Appreciation. Land owned by railroads usually increases in value, the roadbed becomes settled and grassed over and hence of greater value. Such increases in value are called appreciation, and the amount of such increase is somewhat indefinite, although generally recognized by courts and commissions. The Minnesota Commission allowed about 10 per cent of the original cost of roadbed as appreciation in the case of the Northern Pacific Railway but only about 1 per cent in the case of the Minneapolis Western Railway, where the roadbed was not so well seasoned. The Washington Commission stated that roadbed appreciates in value for about five years after construction, when its value is about 10 per cent greater than originally.

Amortization. When provision is made for the extinction or liquidation of a debt at a certain time, the debt is said to be *amortized.* Amortization is usually effected by means of a *sinking fund,* or a fund created by setting aside each year a sum which at compound interest will equal the required amount at the end of the period of time. Debt incurred in securing certain equipment should be amortized at or before the expiration of the life of the equipment. If a property is being operated under a charter or franchise that cannot be renewed, the total investment thereon should be amortized at or before the expiration of the franchise. When, as in the case of most railroads, the franchise is perpetual, there is no special need of amortizing the original investment. Usually, railroad bonds are renewed instead of being paid when due because of necessary extensions on which the railway can use the funds to advantage. Annuity tables are available in any engineering handbook from which the rate of creating a sinking fund for any period may be readily calculated.

Intangible Values. As stated in a previous paragraph, values that depend upon circumstances are commonly called intangible values, the more important items of which may be briefly mentioned. The courts have quite generally recognized the justice of assigning a certain value to those advantages which depend upon circumstance, but the ascertainment of the amount of such values is a matter of great difficulty in many cases, and can rarely be arrived at with anything approaching mathematical exactness. In general the total amount would be the net earnings less the just charges—a reasonable return on capital invested, depreciation, amortization—capitalized at a reasonable rate.

Franchise. The franchise of a public utility is its authority for doing business and has value according to the remunerativeness of the business conducted. Its amount will depend, therefore, upon the earnings of the company and the length of time the franchise has to run before expiration. The weight of authority seems to be against assigning value to franchise in connection with rate making on the supposition that the franchise is more or less a gift from the people to the utility and hence the public should not be compelled to pay a return on the same.

Going Value. There is a great difference between the earning capacity of a railroad or other utility just completed and one that has been operated for some time, or in other words is a going concern. Competent forces must be collected, organized and trained to operate and maintain the equipment, equipment must be "broken in," and errors of design corrected, traffic must be induced by costly advertising, and the good will of the patrons secured; and all of this represents a definite cost, either active or passive. *Good-will value*, which is a factor in going value, has been held to be pertinent to competitive business chiefly rather than to monopolistic business. Going value may be measured by the estimated deficits that will be incurred and the expenditures for promotion in bringing the business of a new plant up to that of the existing one.

Value of Location. Railways have struggled in courts and even with armed forces in the field in certain instances to secure strategic points of location, such as certain river valleys, and gaps and passes through mountain ranges. Such features of the location have a distinct value aside from the price of the land occupied, although it may be rather difficult to determine its amount. One objective that a locating engineer commonly keeps in mind is the occupying of such points and the entrance to such centers of traffic as will prevent the entrance of a competing line. The strategic location of terminals in large cities is another case in point. While the value of location represents in general the difference between the cost of building an equally efficient line on another location and the cost of building the existing line, it is doubtful if this entire amount should inure to the benefit of the railroad in question. Location may have value from two different points of view, viz., that of securing traffic and that of economy in operation. Nearness to centers of traffic and industry comprises the chief factor in the first, while low gradients with easy curves and good roadbed constitute the important factors in the second.

Field Work of Valuation. The various railroads have different modes of making valuation surveys, the mode depending largely upon the magnitude of the undertaking. Perhaps the organization and mode of procedure of the Division of Valuation of the Interstate Commerce Commission will be as instructive as that of any particular railroad in the way of illustration. Under this plan, the entire United States was divided into five districts with an attempt to make each include approximately one-fifth of the railroad mileage. The districts have their headquarters respectively at Washington, Chicago, Chattanooga, Kansas City, and San Francisco. The organization for all divisions is practically identical, with a member of the Board of Engineers in general charge and a district engineer and assistant district engineer specifically in charge. An office engineer in charge of chief computers, squad foremen and computers who do the office work. The field work is in charge of senior engineers who report to the district engineer. The work is divided into five main departments, viz., (1) Mechanical, (2) Roadway and Track, (3) Bridge or Structural, (4) Telegraph, and (5) Signal, each of which has charge of inventorying its respective group of property items. The organization of the first three of these departments is indicated below:

Mechanical

- Senior Mechanical Engineer
  - Mechanical parties
  - Specialists

Roadway and Track

- Senior Civil Engineer
  - Field engineer
  - Asst. field engineer
  - Recorder
  - Instrumentman
  - Computer

Structural

- Senior Structural Engineer
  - Structural field engineer
  - Junior structural engineer
  - Tapeman
  - Specialists

The Interstate Commerce Commission issued in 1914 a tentative draft of instructions to field parties in making valuation surveys from which much of the present paragraph is abstracted. The field party on roadway and track, which may be taken for illustration, consists of two groups, the chaining group comprising a recorder and two chainmen, whose duties consist of locating by stations and plusses all features [illegible] inventoried, and a cross-section group made up of an instrumentman, a rodman and a tapeman, whose duty it is to inventory grading, excavation and tunnels. An assistant field engineer is in charge of each field party who, besides directing the general activities of the party, inventories all special features.

The center line of single track, or on double track the center line between the tracks, is taken as a base line and the chaining stations are numbered on the web of the rail. All surveys are referred to this base line. Each parcel of land that is used in the right of way must be verified and notes made of adjoining land. Not only is the amount of grading measured, but it is also classified as (1) solid rock, (2) loose rock, or (3) common excavation. The condition of slopes is also recorded, and the location, size and character of tunnels obtained. In regard to bridges, the following information is obtained:

1. Railroad number of bridge.
2. Location by station and plus.
3. Kind of culvert, bridge, or trestle.
4. General dimensions.
5. Sketch.
6. Date when built, or rebuilt, if obtainable.

The number of ties is estimated by counting the number under sections of twenty rail lengths at intervals of one-half mile. The brand, weight and section of rails are obtained as well as a description of all frogs, cross-overs and other track material. The kind of ballast is observed and the depth ascertained every 1000 ft. A description also of right-of-way fences, snow and sand fences and snow sheds, crossings and track signs, station, office, and roadway buildings, water and fuel stations, shops and engine houses, telegraphs and telephone lines, signals and interlockers, paving and miscellaneous structures. The assistant engineer makes a note of all abandoned property and records its physical condition.

Determination of Unit Prices. After the inventory of the physical property has been completed, it is necessary to assign unit prices to each of the items, and in the selection of such unit prices, experienced judgment is required, for the final estimate of physical value upon the two elements, viz., the inventory and the unit prices.

The following extract from the statement of the President's

Conference Committee filed with the Interstate Commerce Commission represents, perhaps, as expert opinion as could be found in this connection.

> The prices to be used in the valuation should be arrived at by a consideration of prevailing prices, price tendencies and conditions affecting labor and material markets during a reasonable period of time next preceding and at the date as of which the valuation is to be made, due consideration being given to the existence or non-existence of active railroad construction during that period. The most valuable guide for use in this valuation will be " weighted average " the prices of those commodities which fluctuate violently in price and have no definite price tendency.
>
> The consideration of price tendencies is most important in determining a basis of prices, but it will be more accurate to determine price tendencies with reference to particular commodities rather than with reference to commodities in general because the price tendency of some commodities is upward and of other commodities the price tendency is downward. Periods of active railroad construction coincide with periods of high prices, and periods of stagnation coincide with periods of low prices.

The rate of interest paid on money invested has usually been taken at 6 per cent on the theory that the enterprise would be financed half by bonds bearing 5 per cent and half by stock entitled to 7 per cent. This is probably good practice. The unit prices of construction are further discussed in Chapter XXVI.

CHAPTER V

VOLUME OF TRAFFIC

Introduction. As previously stated, railway location means designing a transportation plant for handling traffic most economically based on the estimated amount and class of traffic, the performance of the motive power to be employed, the resistance to be overcome and the topography to be traversed. The general formula for location commonly given is

$$\frac{R-E}{C}=p,$$

where R = total annual revenues;
E = total annual expenditures;
C = capital invested;
p = percentage of profit.

Obviously the problem of location is to adjust the factors R, E and C so that p will be maximum, and since a railroad is located by fixing its alignment and determining its grades, our study consists essentially of the relationship of grades and alignment to the above factors. Manifestly, the desired result will be secured by making R as great as possible and keeping at the same time E and C as small as possible. The problem of location is therefore a complex one. The following factors will enter into the consideration of the design of a railroad location in addition to the financial and legal influences that have been briefly touched upon in the preceding chapters, which are to an extent extraneous to the strict province of the engineer although necessary for his complete preparation.

1. The estimation of the quantity and class of traffic, number of trains required, and the revenues to be obtained therefrom. In the case of relocations, this factor is definitely known.

2. Locomotive performance, either steam or electric accord-

ing to which is to be used, including the mechanical efficiency and fuel consumption under different conditions of operation.

3. Train resistance and its relation to the total resistance.

4. Railroad operation, including the make-up and conducting of trains, spacing of terminals and sidings and the length of engine districts, additional main tracks, etc.

5. Gradients, including the ruling gradient, length of gradient, etc.

6. Minor details, such as curvatures, distance, rise and fall.

The succeeding chapters will be chiefly occupied by an analysis of the relations of these factors to the general problem of location as stated above.

General Conditions Affecting Volume of Traffic. While it is impossible to make an exact estimate of the amount of traffic that may be expected to come to a proposed railroad, yet as close prediction as possible is essential for a satisfactory solution of the problem. A variety of conditions influence the amount of business of a railroad, such as the nearness of competing lines, 2 ✓the fertility of the soil in the region traversed, the character and 3 prosperity of the people served, the topography of the country 4 and the kind of highways leading to the stations. 5

In the early days when a railroad was being built the promoters counted on all traffic within easy reach of the right of way, since there were not many competing roads. At that time, the railroad mileage was perhaps 2 per cent of what it is at present; an area of 100 miles square (10,000 square miles) was served then by perhaps 10 miles of railroad, on an average over the country, whereas now, such an area contains about 860 miles. Railroads were built not only to carry the traffic already existing, but to stimulate the growth of the country and thus develop additional business. While a few branch lines are still being constructed into new territory unserved by any railroad, the lines that are being built lie chiefly in territory where competition will be encountered to a greater or less extent. There are at present in the United States enough miles of railroad to construct a gridiron network made up of lines 20 miles apart running east and west and north and south across the country, so that no point would be more than 10 miles from a railroad in either direction. The existing lines are laid out of course in no such mechanical fashion, but have been built chiefly to connect the centers of population, the location of which has been controlled mainly by the nature of the country. There are mountainous and other unproductive districts where railroads could never find enough business to justify their construction, while, on the other hand, a veritable network of roads exist in other parts where conditions are more favorable.

The character of the soil so far as agricultural shipping is concerned has much to do with the amount of traffic. The amount of grain, live stock, dairy products, poultry, and other farm products received from Illinois, Iowa, Minnesota and other notably productive states stands in marked contrast to the amount received from arid or hilly regions. The fertility of the soil is very closely related to the thrift and intelligence of the inhabitants in regard to improved methods of cultivation. The policy of the Northern Pacific Railroad, as well as many other lines, has been to take active steps to promote thrift and industry and improvement in agricultural methods, chiefly by the distribution of literature relating to these matters and by the arrangement of lecture bureaus. All of these matters should be taken into consideration when any estimate of traffic is being made involving a comparison with other roads.

Character of Towns. To a certain extent, the character of the centers of population, i.e., the cities and towns, along the proposed route will give a direct indication of the amount and the nature of the traffic to be expected, for such centers of population are largely a measure of the surrounding country as well as showing what business may be expected from them directly. Cities and towns may be grouped into certain classes as regards their chief industries, and such a classification is useful in studying the customs and activities of the inhabitants.

1. Agricultural towns, or those surrounded by good farming regions, are very stable in their population, usually enjoying a steady although not rapid growth, and the amount of business derived from such towns does not vary greatly from year to year.

2. Mining towns are the most erratic in their nature of all these groups, the population being of a shifting or transient sort. The amount of business coming from such places may be very heavy during industrial peace and in times of prosperity, but strikes and unfavorable financial conditions usually affect such centers of population most acutely.

3. Small manufacturing cities where only one or two principal industrial plants are located generally are somewhat spasmodic in their activity.

4. Pleasure resorts merit notice only as they may affect passenger traffic. The amount of business coming from such will fluctuate with the season.

5. Large metropolitan cities, with their great variety of industries, are comparatively stable in most respects, generally showing no sudden changes in their commerce, although their traffic may vary gradually with the seasons and with cycles of general prosperity and depression.

6. Seaports furnish a definite source of business apart from the manufacturing industries of the cities themselves owing to the export and import shipping.

In a general way, the large cities of the United States east of the Rocky Mountains serve the territory west of them rather than that east of them. The rural produce is shipped eastward and the supplies of the cities sent westward, and in all other phases of the natural social and commercial relationship existing between a city and rural population the large cities of the country serve and are served in turn by the country west of them.

Highways. The highways of the country should be considered as essentially complementary to the railroads, the two together constituting the commercial circulatory system, the railways being the arteries and veins and the highways the capillaries. It will rarely happen that the highways will enter into competition with the railroads, except for very short hauls, although, through the extended use of the automobile and the auto-truck, improved highways may in some cases actually conduct some transportation that would otherwise go over the railroads. Such conditions may cut some figure in local traffic and interurban business, but would scarcely affect to any appreciable extent traffic of commerce between points located considerable distances apart.

Owing to the fact that the highways must be depended upon to care for the transportation to and from the railway stations, it is greatly to the railway's interest to promote the construction and maintenance of good country roads and city streets. The question that confronts the prospective shipper is the total cost of transportation from his door to that of the consignee, and one considerable factor that enters into this cost is the cost of local carriage over city streets or country roads. While good roads at present may not affect the total amount of traffic by a large percentage, they greatly influence the distribution of such traffic throughout the year, since they make it possible to market grain, live stock and other farm produce at any time of the season.

Classification of Freight Traffic. The subject of freight classification is a very complex one. The classification may be (1) for rate making purposes, in which it is more or less arbitrary, depending somewhat upon the value and character of the goods, (2) according to the origin of the commodities, (3) according to the source, (4) according to the manner in which the freight is handled, or (5) according to the speed with which it is carried over the line.

The classification for rate-making purposes will be taken up in another chapter in connection with rate making.

With reference to the origin of commodities, the Interstate Commerce Commission recognizes seven classes, which are of particular interest in considering the volume of traffic over a railroad. They are as follows:

1. Products of Agriculture: Grain, flour, other mill products, hay, tobacco, cotton and cottonseed products, fruit, potatoes, vegetables, canned goods.
2. Animal and Animal Products: Live stock, dressed meats, other packing-house products, poultry, dairy products, game and fish, wool, hides, leather, eggs, and other animal products.
3. Products of Mines: Coal, coke, ore, and bullion, stone, sand, crude petroleum, salt, and other mineral products.
4. Forest Products: Lumber, lath, shingles, ties, etc.
5. Manufactures: Oil (except crude petroleum and cottonseed), sugar, naval store, iron (pig and bloom), iron and steel rails, castings, machinery, bar and sheet metal, cement, brick, tile, lime, wagons, carriages, tools, liquors, nails, etc.
6. Merchandise: Cloth, clothing, groceries, etc.
7. Miscellaneous: L. C. L. household goods and other L. C. L. freight.

Table I gives a general notion of the amount of traffic derived from each of these classes. A study of the percentages representing the several amounts of the commodities named for the country

TABLE I

PROPORTION OF FREIGHT DERIVED FROM EACH CLASS[1]

Railroad.	Total Tonnage, 000 omitted	Agric. Products. Per cent	Animal Products. Per cent	Mine Products. Per cent	Forest Products. Per cent	Manufactures Per cent	Merchandise. Per cent	Miscellaneous Per cent
1911				✓		✓		
A., T. & S.F.	16,390	22.15	8.07	32.53	9.48	19.54	7.16	1.07
C. B. & Q.	28,328	18.68	7.93	37.87	7.75	6.88	7.02	13.87
C. G. W.	5,023	28.18	6.66	29.45	6.82	22.31	6.08	1.50
C. M. & St. P. ...	26,794	21.42	6.43	26.82	13.52	17.55	11.04	3.22
C. & N. W.	36,734	14.57	5.20	41.81	14.50	14.30	6.26	3.36
C. R. I. & P.	18,729	26.10	7.70	28.88	11.72	18.60	6.60	0.40
Gt. Northern ...	23,071	14.04	1.39	63.81	10.62	5.55	3.12	1.47
U. P.	9,666	25.98	8.55	32.62	6.59	17.81	5.72	2.73
Wabash	14,137	18.66	8.63	31.77	7.69	22.92	7.18	3.15
1912								
Eastern District. .	....	7.13	1.93	59.60	5.61	17.56	3.10	5.44
Southern District.	....	11.27	1.72	49.09	17.11	13.47	4.77	2.57
Western District.	....	16.50	4.05	44.00	16.35	12.22	4.86	2.02
United States	....	10.03	2.42	54.27	9.88	15.66	3.77	3.97

as a whole and for the three districts as well as for the separate roads will throw some light upon the commercial conditions which affect railway revenues and management. Mine products and manufactured products are predominant in the eastern part of the country while agricultural products and forest products constitute the larger percentage of business in the western part of the country than in the eastern part.

In regard to the source of freight, it is classified into two divisions, namely, (1) that which originates on the line and (2) that which comes from other railroads. From Table II it will be observed that for the entire United States, the freight is about equally divided between that originating on the line and that received from other carriers, the former preponderating in the western and southern districts while the reverse is true in the eastern district.

With respect to loading, freight is divided into two classes, viz., car load (C. L.) and less than car load (L. C. L.), the latter being called sometimes peddler, parcel, package, or platform freight by different railroads. Less than car load freight consti-

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[1] Report, Railroad Commission of Iowa, 1911

TABLE II

PER CENT OF FREIGHT TONNAGE ORIGINATING ON THE LINE

Class.	Eastern District.		Southern District.		Western District.		United States.	
	On Line.	From Connecting Carriers	On Line.	From Connecting Carriers	On Line.	From Connecting Carriers	On Line.	From Connecting Carriers
Products of Agriculture.	2.16	4.86	5.53	5.70	13.00	5.32	5.44	5.08
Products of Animals.	0.85	1.11	1.20	0.80	3.00	0.94	1.45	1.02
Products of Mines. ..	28.50	31.60	39.40	10.30	34.38	8.28	31.60	22.60
Products of Forests..	1.72	3.90	10.40	6.36	9.70	5.37	5.02	4.63
Manufactures.......	8.45	9.07	7.24	5.88	6.68	6.42	7.82	7.95
Merchandise........	1.42	1.36	2.91	1.99	3.69	1.42	2.21	1.46
Miscellaneous...	2.40	2.50	1.23	1.11	1.38	0.42	1.98	1.74
Total............	45.60	54.40	67.91	32.09	71.83	28.17	55.52	44.48

tutes a relatively small proportion of the total bulk of freight hauled, but a much larger proportion of the total revenues received on account of the higher rates charged. The following data show typical rates for various commodities carried in car load lots:

	Cents per Ton-Mile
Grain................................	0.626
Hay................................	1.014
Cotton................................	1.716
Live stock................................	1.214
Dressed meat........................	0.960
Anthracite coal........................	0.570
Bituminous coal........................	0.468
Lumber.	0.701

Traffic per Mile of Road. While the traffic per mile of road for existing lines may not have much significance directly as an aid in estimating the volume of traffic of a proposed line, yet as a general guide and as a check on other estimates it may have value. The traffic per mile will obviously depend upon the density of the population in the region served and the amount of shipping that this population offers to the road. However, the area of timber land, of farm land and of mining lands may be considered to be roughly proportional to the length of line and the yield of the commodities from such areas will depend upon the area worked as well as on the population working them. In regard to the agricultural products, an increase in population along the line may actually cause a decrease in the amount of shipping owing to the fact that the more intensive farming of the larger population does not increase the yield in proportion to the population, and since the local requirements are greater the amount shipped out is less. In some cases, extensive farming furnishes large shipments of grain and live stock which farming on a smaller scale does not afford. Table III gives the traffic per mile of line for twenty of the more important railroads of the United States and the average of the United States. Some shorter lines constructed for special traffic, such as coal or ore, have much higher receipts per mile than the ones listed.

TABLE III
ANNUAL TRAFFIC PER MILE OF ROAD
1915

Railroad.	Mileage.	Freight, Tons.	Passengers	Freight, Ton-miles.	Passenger, Miles.
Pennsylvania	4,528	27,300	16,720	4,700,000	422,000
N. Y. C. & H. R.	3,709	7,800	8,120	1,392,000	268,000
Balt. & Ohio	4,535	14,170	4,520	2,860,000	158,000
D., L. & W	957	23,500	25,200	4,350,000	557,000
N. Y., N. H. & H.	2,003	11,900	39,100	1,092,000	738,000
Wabash	2,518	5,350	2,200	1,280,000	124,000
P. & L. E.	225	117,000	18,800	7,220,000	380,000
Mobile & Ohio	1,122	5,640	1,620	1,300,000	49,600
Nash., Chatt. & St. L.	1,230	3,850	2,450	596,000	98,200
So. Pacific	6,514	2,910	5,560	654,000	198,000
A., T. & S. F	8,492	2,600	1,400	747,000	139,000
C., M. & St. P	10,053	3,290	1,600	818,500	85,800
C., B. & Q	9,339	3,400	2,430	914,000	115,500
C. & N. W	8,107	4,980	4,080	766,000	139,500
Gt. Northern	8,060	2,910	1,050	715,000	71,500
Nor. Pacific	6,461	2,730	1,350	800,000	92,800
Union Pacific	3,616	2,910	1,230	1,050,000	133,000
M., K. & T	3,865	2,630	1,700	586,000	92,800
D. & R. G.	2,571	3,440	600	522,000	89,500
Ore. Short Line	2,165	2,550	960	691,000	79,000
United States	......	7,920	4,230	1,116,000	114,000

Traffic per Capita. To estimate the traffic per capita and then to estimate the tributary population may serve as another means of arriving at the amount of business that may be expected, although such a diversity exists in the thrift and the needs of communities that this method affords no very specific information. For the entire United States, the traffic per capita is shown below for the years 1890, 1900 and 1910.

Year.	Passenger-miles per Capita.	Ton-miles per Capita.	Population per Square Mile.
1890	188	1295	23
1900	221	1860	28
1910	352	2780	34

These figures show that in 1910, for example, the passenger-miles per capita was equivalent to a ride from Chicago to Cleveland and the ton-miles per capita was equivalent to hauling a ton of freight from New York to Omaha for each man, woman and child in the country. Incidentally the above figures show the tendency of traffic per capita to increase with the density of population, a matter that will be considered at another place. Table IV shows the passenger service per capita for 1912 in each of the ten groups of territory into which the United States is divided by the Interstate Commerce Commission and Table V shows the freight service per capita in a like manner.

TABLE IV

PASSENGER SERVICE PER CAPITA

Group.	Pass.-mi. per Capita.	Av. No. Pass. in Train.	Average Journey. Miles.	Receipts, Cts. per Pass.-mile.	Population per Sq. Mile.
I.	540	76	20	1.72	83
II.	354	63	23	1.70	178
III.	394	51	41	1.85	79
IV.	154	42	36	2.18	47
V.	184	41	40	2.26	39
VI.	422	53	41	1.89	39
VII.	605	60	94	2.07	6
VIII.	386	49	54	2.08	24
IX.	216	48	53	2.32	15
X.	583	67	48	2.29	7
U. S.	354	56	34	1.94	34

TABLE V

FREIGHT TRAFFIC PER CAPITA

Group.	Ton-miles per Capita.	Av. Train Load, Tons.	Av. Haul per Ton, Miles.	Receipts per Ton-mile, Cts.
I.	1260	263	93	1.12
II.	3170	502	127	.64
III.	5000	457	116	.59
IV.	2050	423	192	.66
V.	1650	278	150	.80
VI.	3330	359	140	.75
VII.	4130	375	271	.95
VIII.	2430	263	183	.97
IX.	1330	239	131	1.06
X.	2400	369	174	1.20
U. S.	2800	380	138	.75

From the above tables, it is obvious that averages do not show a very definite figure which may be taken as the amount of passenger or freight traffic per capita that may be expected on a proposed road, yet a rough estimate of probable traffic may be made from these figures. The smaller amount of business per capita in Groups IV and V is probably due to the large proportion of inefficient negro population in the states composing those sections.

Estimate of Tributary Population. To complete the estimate of the probable traffic originating on the line from the consideration of the tributary population, it is necessary, after assigning a value to the amount per capita, to make some assumption or estimate as to the number of persons tributary to the proposed railroad. The following general assumptions might be made to assist in determining this factor: (1) The railroad serves the entire population of towns having no other railroad. (2) In those cities and towns which are served by two or more railroads, the population may be divided between them in proportion to the mileage of the railroads, provided equal terminal facilities are afforded. (3) All rural population within teaming distance of the line which is not nearer another road and which is not cut off from the line by some natural barrier, such as a river, steep hills, etc., may be considered as furnishing its per capita quota of traffic. The population of these communities can be obtained from census reports, the tributary population bearing the same relation to the township population as the tributary area does to the area of the township. By taking the product of the tributary population and the traffic per capita, a proximate estimate of the probable traffic may be obtained.

Comparison with Other Railroads. The amount of traffic carried by roads similarly situated may be a valuable check on any computed estimates that may be made concerning the volume of business that may be expected. In making a comparison of this sort, the surrounding conditions should be taken into consideration, such as the density of population, the amount of business done in the cities served as indicated by the bank clearings or some other measure of commercial activity, the general productiveness of the region, and the thrift of the people. The nature of the freight, whether it be agricultural, mineral, manufactures, etc., should be carefully investigated to ascertain whether or not the conditions are similar. Obviously, a road like the Delaware, Lackawanna and Western (see p. 78) should not be compared with one like the Great Northern or the Missouri Pacific, while a study of the former might aid in predicting the traffic of one like the Duluth and Iron Range and a study of the latter two might throw light on the probable operating conditions on a road like the St. Louis and San Francisco. The reports of the Interstate Commerce Commission and of the state commissions are available for conducting studies of this kind.

Estimate from Sources of Traffic. The most reliable, although the most expensive, method of forming a reasonably close estimate of the traffic to be expected is to make a detailed study of the actual sources of traffic along the proposed route. This consists in listing in detail the manufacturing plants and their output, the lumbering camps, the mines, the stores and their requirements, the larger farms, and making an average of the smaller farms. This method would doubtless result in an understatement of the traffic, for any store or factory or other industry would doubtless have its business greatly stimulated and increased by the introduction of the conveniences that the railroad would offer. For this reason, statistics of this sort should include not only present business, but also that which would likely result from the improved transportation facilities.

Effect of Proximity to Source of Traffic. Upon the convenience of the transportation facilities offered by a railroad company will depend the amount of traffic received to a very great extent. In the early days of railroads, it was customary for trains to stop at farms along the way for the purpose of unloading farm implements and taking on produce. Even now, railroads entering into large cities find it advisable to establish milk stations at frequent intervals along the right of way. The question as to how far such facilities may be extended is an economic one and is not easily answered. Mr. A. M. Wellington in his " Economic Theory of Railway Location " discusses the general situation as follows:

" With the invention of the railway first began the manufacture of transportation for sale on a large scale and by modern processes. A railway corporation . . . exists for this purpose. It finds itself, on completion of its work, in possession of a certain improved piece of real estate, of certain buildings and fixed machinery (the track), and of certain tools and machines (the rolling stock) for the manufacture of its commodities, together with certain establishments (the locomotive and car shops) for the maintenance and repair of its machine tools, which the extent of its business requires. . . .

" On the premises so rented, the corporation carries on, for its own benefit, the business of manufacturing and selling transportation, so to speak, at wholesale and retail, in lots to suit the purchasers. . . .

" Now continuing the parallel, which will perhaps help to enforce the truths required, and referring only to sales of transportation, or revenue: if a manufacturing company in such circumstances should, in planning its works, so plan them as to cut itself off from disposing certain lines of goods which it manufactures, or should place its retail establishments (stations) at inconvenient points, it is clear that it would have seriously handicapped itself, even if, perchance, justifiably. This a railway does when, by failing to run close to any accessible towns, it is prevented from furnishing them with transportation, or it is so far away that sales are inconvenient. . . .

" The force of this parallel is still further and greatly strengthened if we remember that, with much that is similar, there is in one respect, a momentous and broad distinction between the seller of transportation [illegible] the seller of other commodities. The production, or pa[illegible]tion of transportation is, from the necessity of the business, considerably in excess of the amount sold, and its cost bears an irregular ratio thereto. Every time, for example, a passenger train starts out, there is 'manufactured,' so to speak, several hundred passenger trips. If they be not sold, they cannot be stored away until the next day's trade, like the remnants of a lot of dry goods. They are simply wasted and thrown away. It is with the railroad much as if the tradesman were compelled to cut a new piece of each kind of goods each day and then throw away the part remaining unsold each night."

Obviously, therefore, it is desirable to afford all the convenience possible that will bring in more traffic and which will produce returns in proportion to the outlay. In England, the railways collect and deliver the freight directly from and to the customer's door to a great extent. The horse or the motor vans of the railway call at the consignor's warehouse for the freight to be shipped and then other vans deliver the goods when they arrive at their destination. Where this custom is not followed, as in the United States, other means of promoting convenience must be considered. Two possible ways of doing this suggest themselves, viz., (*a*) placing the stations near the centers of towns and (*b*) placing station stops and sidings at frequent intervals along the line.

Location of Station with Reference to Center of Town. In those instances where a railroad has a monopoly of the traffic at a certain point, it will get all of the shipping at that point to be had even though its local facilities are not conveniently situated. However, convenient shipping facilities always stimulate and create traffic to a considerable extent, and moreover, even though the railroad may enjoy a monopoly in the beginning it may not continue to do so unless its shipping facilities are such as to satisfy the needs of the people served. On the other hand, when the element of competition enters, the amount of business that any one road will secure will depend very largely upon the convenience of the local shipping facilities, for the patron figures transportation costs from his door or the door of his warehouse to the destination and includes drayage or other charges as well as freight, and consequently any additional charge such as drayage or cab hire will work to the detriment of the railroad.

Frequently railroads have sought to economize by locating their stations at a distance from the center of towns on real estate that was much less expensive than that situated in the heart of the towns. This policy is false economy, as the history of every road that has tried it will demonstrate. Mr. Wellington well said that such a course was like building all the spans of a long bridge but one and then operating that one by a ferry because it was a short one.

Examples that illustrate these facts readily occur to the mind of anyone who has had opportunity to observe the railroads at different cities and to study the corresponding traffic conditions. The New York, Chicago and St. Louis R. R. (Nickel Plate) competes at various points along its line with the Pennsylvania and with the Lake Shore and Michigan Southern railways at a very great disadvantage because its stations are located far from the centers of the towns. As a result, the latter roads carry the choice of the traffic, that is, the most profitable traffic, while the former must be content with carrying small shipments and otherwise less desirable business. For example, at Valparaiso, Indiana, the Pennsylvania Railroad carries practically all of the traffic because the Nickel Plate station is about half a mile past the Pennsylvania station and the Grand Trunk station is still farther away in another direction. At Gary, however, only about 15 miles away, the Pennsylvania suffers because its depot is over a mile from the center of the city owing to the fact that the latter was built entirely after the railroad was well established. It is due to the unexcelled service which the Pennsylvania offers in other respects that it secures any considerable portion of the traffic from this point, because the Lake Shore furnished a handsome and commodious station in the heart of the city. The enormous sum of money spent by the Pennsylvania in securing a station on Manhattan Island at New York, thereby obtaining an advantage over those lines having termini on the west shore of the North River and at the same time placing its stations on a par with the Grand Central Station of the New York Central lines, which is in the heart of the city, is another illustration of the fact that railroads act upon this principle so far as practicable. The disadvantage formerly accruing to the Denver, Northwestern and Pacific at Denver in not being able to enter the Union depot, to the Delaware, Lackawanna and Western at Paterson, N. J., because of the long haul to the station and the hill in addition, to the Rock Island at Peoria, Illinois, in not entering the Union station, to the Union Pacific at Lawrence, Kansas, where in addition to the greater distance, a long bridge must be crossed, further illustrate the principle involved. The Pennsylvania road obtains by far the major portion of the traffic between Philadelphia and Baltimore largely because of the proximity and commodiousness of the Broad Street Station in comparison with the facilities offered by its chief competitor, the Baltimore and Ohio. Sometimes, however, the arrangement of local transportation lines, such as street cars, subway and elevated railways may offset to a great extent the disadvantages of mere distance, but too great weight should not be attached to such conditions because the local conditions are likely to adjust themselves in accordance with the needs of the case and thus alter the situation, in this respect. Wellington estimated that a road would lose from 10 per cent under non-competitive conditions to 50 per cent under sharply competitive conditions of the traffic normally coming to the road for each mile the station is from the business center.

Frequency of Station Stops. The distance between station stops is not always within the control of the railroad, but the spacing of stations and intermediate sidings should receive careful consideration. Naturally, stations will be established at all existing towns through which the line passes, but it may be desirable to arrange sidings and stops between the towns in order to accommodate the traffic of thickly populated rural sections. The cost of lost time and of starting and stopping the trains must be balanced against the added revenue obtained by fixing the extra stop or siding. Usually the smaller stations are operated as flag stops for passenger trains, and consequently stops would not need to be made unless passengers were actually to be received or passengers were to alight at such places. The proper interval between sidings depends chiefly upon the character of the country traversed. In the rich agricultural regions of some of the Middle Western states, station stops for passengers are provided about 5 to 7 miles apart, with sidings for freight at such points and frequently between such stations also. About 3 to 5 miles constitute the maximum haul desirable for farm produce to market and the sidings should be spaced so as to enable the farm produce to be loaded on cars without greatly exceeding this limit.

Traffic from Connecting Lines. Besides the traffic that originates on the line, the traffic that may be derived from connecting lines should be carefully considered, for it may amount to more in some instances than the former item. As a matter of fact, the success of many lines is due more to their favorable connections than to the productiveness of the country traversed. Small lines are acquired by larger roads as feeders and the main line traffic may consist chiefly of that received from connecting lines. Table VI indicates the proportion of traffic originating on the line and that received from connecting lines in the state of Indiana for the year 1911. It is probable that many short lines will be constructed in this country in the future to serve as connecting links between existing branches, and consequently over such lines the traffic received from connecting carriers will largely constitute a major portion of the total business.

TABLE VI

PROPORTION OF FREIGHT RECEIVED FROM CONNECTING LINES

Railroad.	Per cent Originating on Line.	Per cent Received from Connecting Carriers.
Baltimore & Ohio	17.8	82.2
Chesapeake & Ohio	28.2	71.8
Chic. & E. Ill	67.0	33.0
Chic., Ind. & Louisville	61.5	38.5
C., C., C. & St. L.	38.4	61.6
E. J. & E.	54.6	45.4
L. E. & W.	38.4	61.6
L. S. & M. S.	26.6	73.4
Mich. Central	10.4	89.6
N. Y. C. & St. L.	22.1	77.9
T., St. L. & W.	40.6	59.4
Vandalia	66.2	33.8

Volume of Traffic a Function of the Population. From the previous paragraphs it is evident that traffic increases with the population in some ratio and in the present paragraph an attempt will be made to investigate the relation which the volume of traffic bears to the population, first analytically and then by a study of statistical data.

The following illustration is adapted from Wellington. Suppose two choices of route are offered between the points A and B, one direct and the other, by a slight detour, including C. What will be the relative amounts of traffic? Assume points A, B and C to be equal in size. The result is that instead of merely the traffic A–B, the traffic units A–C and B–C are opened, which would about double the traffic A–B. Owing to the fact that nearness of cities tends greatly to augment the amount of traffic between them, the actual tonnage between A and C or between B and C will be much greater than it would have been for the direct route between A and B. Due to this fact, the traffic would doubtless be tripled instead of doubled. By introducing the points D and E on the lines A–C and B–C respectively, ten choices result, viz., A–B, A–C, C–B, A–D, D–C, C–E, A–E, B–D, D–E, B–E. Generalizing, the results may be set down thus,

No. of routes	2	3	4	5	n
Traffic ratio	1	$1+2$	$1+2+3$	$1+2+3+4$	$1+2+3+4+\ldots(n-1)$

That is, for n points of traffic there are $1+2+3+4 \ . \ . \ . \ (n-1)$, or $\frac{n(n+1)}{2}$, choices of traffic routes.

The conclusion may then be drawn, if it is assumed that these traffic units remain equal, which would doubtless be true as a minimum condition, for, as indicated above, the traffic would probably increase with proximity of sources of traffic, that the comparison of traffic volumes under two conditions would be

$$\frac{N(N-1)}{n(n-1)},$$

where N and n represent the number of centers of traffic under the two conditions. If N and n are considerable size, this ratio amounts to N^2/n^2. That is, according to this analysis, the volume of traffic varies as the square of the tributary sources of traffic. That nearness of centers of population so stimulates traffic that the loss of train mileage due to decreased distance is more than compensated for by the increase of actual tonnage and passengers hauled is a fact borne out by experience.

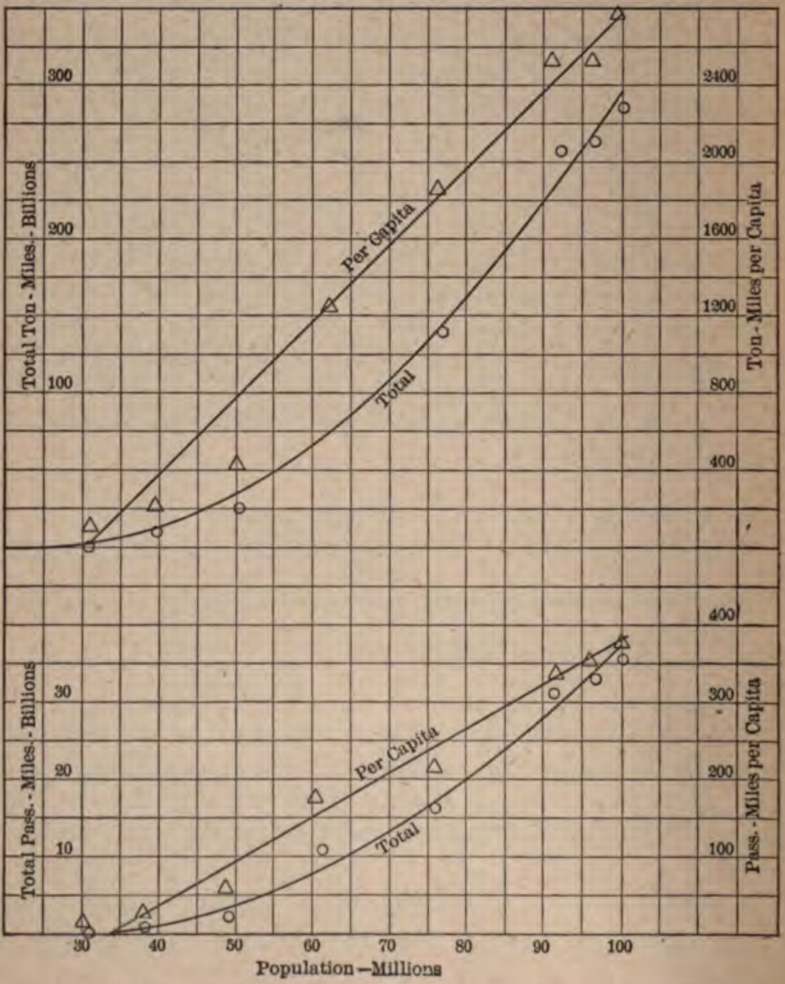

FIG. 5.—Relation between Traffic and Population in the United States.

The curves of Fig. 5 show the growth of freight and passenger traffic in the United States with the increase in population. From these curves, it is evident that the traffic can be expressed as an exponential function of the population. If the curves showing the traffic per capita were taken as a straight line, then the total traffic would obviously increase as the square of the population as indicated in the preceding paragraph. The equation may be represented thus,

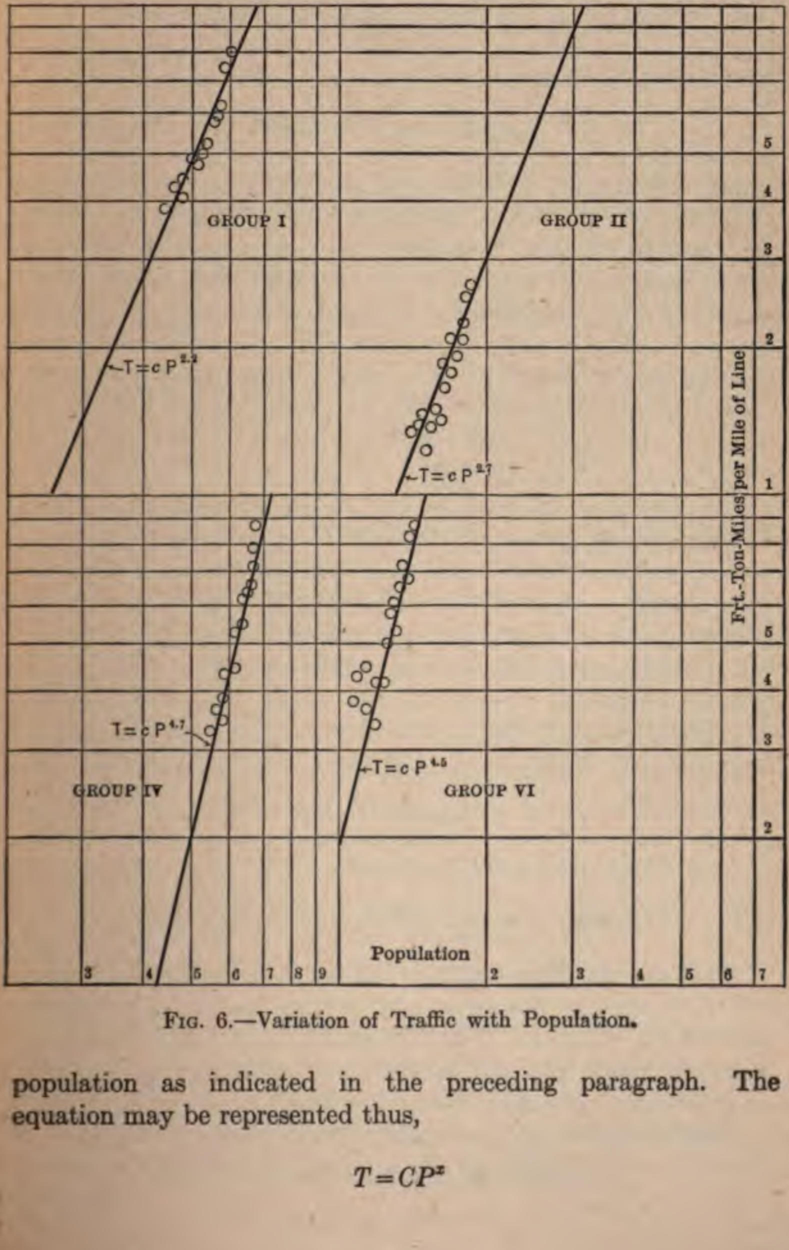

FIG. 6.—Variation of Traffic with Population.

$$T = CP^x$$

where T represents the traffic
P the population;
C being a coefficient;
x being an unknown exponent.

By plotting this equation on logarithmic paper as

$$\text{Log } T=\log C+x \log P,$$

using ton-miles as ordinates and population ratios as abscissas, the value of the slope x may be obtained without considering the constant C. This was done form the records of the Interstate Commerce Commission for the territorial groups designated by the Commission.* Fig. 6 shows this relation for Groups I, II, IV and VI. Table VII gives the results from plotting similar curves for the entire United States and for the other Interstate Commerce. Commission groups, also for the different classes of freight and for freight originating on the line.

To illustrate the use of the table, suppose it is desired to estimate the increase in traffic due to an increase in population of 20 per cent for a railroad operating under commercial conditions similar to those of Group V. For this group, the relation between traffic and population is represented by $T=CP^4$. Let the original population be represented as unity, then the increased population will be represented by 1.2. Suppose there were 56,000 tons of freight carried under the former conditions, as in the case of the Mobile and Ohio Railway, Table III, then

$$56{,}000=Cx1^4,$$

or $C=56{,}000$ for these conditions,

and $T=56{,}000\times 1.2^4=106{,}000$ tons for the new conditions.

Mail and Express Traffic. The revenues received for carrying U. S. mail are determined by average weighings in different parts of the country. These weighings are made quadrennially and each weighing establishes the amount of pay that the railroads receive for carrying mail for the succeeding four years. Although for the carrying of mails there has been a gradual increase

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* Journal Assoc. Eng. Soc., Vol. XLVI, p. 218.

TABLE VII

VARIATION OF TRAFFIC WITH POPULATION

$$T = CP^x$$

T = Ton-miles. P = Population. C = Coef.

Territory.	Commodity.		VALUE OF x.	
			App.	Actual.
United States....	Total..............	Carried 1 mile......	3	2.9
Group I.........	"	" "	2.5	2.2
Group II........	"	" "	3	2.7
Group III.......	"	" "	6	5.5
Group IV.......	"	" "	5	4.7
Group V........	"	" "	4	4.3
Group VI.......	"	" "	4	4.5
Group VII.......	"	" "	8	8.3
Group VIII......	"	" "	3	3.4
Group IX.......	"	" "	2	2.3
Group X........	"	" "	3	3.4
United States....	"	Originating on line..	5	4.8
Division I.......	"	" "	6	6.1
Division II......	"	" "	6	5.5
Division III.....	"	" "	5	4.7
United States....	Animal products...	" "	2	2.0
" "	Agric. products....	" "	2	2.0
" "	Mine products.....	" "	5	5.0
" "	Forest products....	" "	4	4.3
" "	Manuf. products...	" "	7	7.1
" "	Mer'd'se.........	" "	5	5.0

in the actual receipts, yet the service rendered has also greatly increased, and, as a matter of fact, the revenues from this source have by no means kept pace with the earnings from other sources. In 1913, these were 1353 full railway post-office cars in use and in reserve, of which 596 were all steel cars, 201 steel underframe cars and 556 wooden cars. In addition to these, there were 4120 apartment cars in use and in reserve, of which 354 were all-steel cars.

The receipts for carrying packages for express companies are larger than those from carrying mail. Out of every dollar taken in by the express companies, the railroads get from 45 to 55 cents. Mail contributes on an average for the United States, 1.6 per cent of the total earnings while express furnishes 2.5 per cent.

Traffic on Interurban Lines. The traffic on electric interurban railways is chiefly confined to passenger transportation, although several such lines are hauling express and freight profitably. Because of the greater convenience of interurban travel in many instances, interurban lines have made serious inroads on the local passenger business of steam roads in many cases. For example, the following figures show the falling off of passenger travel between Cleveland and Oberlin, Ohio, on the Lake Shore and Michigan Southern Railway after an electric interurban line had been constructed joining these two points:

PASSENGERS CARRIED

	Total.	West Bound.	East Bound.
1895	203,014	184,426	98,588
1902	91,761	46,328	45,433

Table VIII shows the revenue from some interurban railways in the state of Illinois for the year 1912.

Importance of Large Gross Revenues. The universal experience of railroads has been that they have had a small margin between gross earnings and gross expenditures, and to increase this margin is the chief problem of railway operation and the possibilities of widening this margin should be ever kept in the mind of the locating engineer. Fixed charges vary but little if at all with the volume of traffic, and it will be seen later that operating expenses do not increase by any means in proportion to an augmented traffic, nor do they decrease proportionally with a diminished traffic. General operating expenses are almost independent of the amount of traffic carried while those expenses more intimately connected with train operation are more or less affected, but never in proportion to the increase or decrease in the amount of traffic handled. Each additional train costs less per train mile than do those already operating, while the revenues depend directly upon the amount of traffic. From these considerations, the importance of securing the largest possible gross revenues is obvious.

TABLE VIII

TRAFFIC ON ELECTRIC RAILROADS OF ILLINOIS

1912

Company.	Miles of Line.	Passenger Revenue.	Baggage Rev.	Parlor, Chair, and Special Car Rev.	Mail Rev.	Express Rev.	Milk Rev.	Freight Rev.	Switching Rev.	Miscellaneous Transportation Rev.	Total Revenue from Transportation.
Alton, Granite & St. L. Tr. Co.	52.3	408,558	....	....	199	6,709	....	......	......	......	415,466
Aurora, Elgin & Chic. R. R. Co.	130.1	1,496,182	....	....	442	48,907	22,230	12,884	......	1108	1,581,753
Bloomington, Pontiac & Joliet El. Ry.	19.4	19,876	110	100	....	1,965	67	......	115	898	23,137
Cairo & St. Louis Ry. Co.	8.3	39,311	....	....	249	7,187	708	......	......	......	47,455
Chic. & Inter. Tract. Co.	45.6	68,370	....	980	....	1,305	213	2,536	......	811	74,245
Chic. & Joliet El. Ry. Co.	48.8	475,345	....	2,439	....	2,592	....	954	3,414	92	484,836
Illinois Traction System:											
Bloomington, Decatur Champaign	92.8	339,697	5226	3,947	....	11,974	2,803	52,884	......	60	417,591
Danville & E. Illinois Ry. Co.	2.0	3,303	....	....	....	....	....	......	......	......	3,303
Danville & S. E. Ry. Co.	3.0	1,918	....	....	....	....	....	......	......	......	1,918
Danville, Urbana, & Champaign Ry. Co	61.9	359,116	3566	2,673	1703	5,150	493	53,892	12,824	116	449,563
Illinois Central Tr. Co.	42.9	196,042	3156	3,027	506	5,917	559	35,471	180	19	245,177
Springfield & Northeastern Tr. Co.	28.6	53,970	680	1,518	....	3,052	250	25,793	33	4	95,300
St. Louis El. Terminal Ry. Co.	5.5	69,955	199	1,755	....	238	736	12,508	1,483	352	87,226
St. Louis, Spfd. & Peoria R. R.	221.5	761,870	8972	19,718	600	22,126	16,915	217,985	246	2429	1,050,369

CHAPTER VI

OPERATING EXPENSES

Definition. It is not an easy matter to frame an entirely satisfactory definition of operating expenses as the term has been variously interpreted by the Interstate Commerce Commission and the different state railroad commissions. Given a railroad plant in normal state of repair, the operating expenses are those involved in conducting traffic over the railroad and in maintaining the railroad in its original condition. In an industry whose organization and processes are simple, the separating out of operating expenses is not difficult. In such a case, the income is easily stated, the operating expenses readily calculated, and the profit thereby directly determined. In the case of a railroad, however, the matter is very complex. In the first place, it is difficult to distinguish between the expenditures made in operation and those made in creating the plant, that is, between real operating expenses and capital charges. For example, when small tools, waste or other similar items are purchased, while they may replace other equipment, they add to the physical plant and, in a sense are, therefore capital charges, yet such expenditures would be classed as operating expenses. The Interstate Commerce Commission has ruled that in general when any equipment is purchased to replace old equipment, the cost of replacing the old is charged to operating expenses and the remainder of the purchase price is charged to Additions and Betterments, which is a capital account. This principle is applied in the decision of all cases of this sort and should be kept clearly in mind.

Depreciation as an Operating Expense. In a previous chapter, the nature of depreciation was discussed, and in general it was found that depreciation is a charge made to cover deterioration of the specific parts of the physical plant due to wear or passage of time. Some have argued that depreciation should be a capital charge since, it represents a lessening of the value of the physical plant. In the case of railroads, however, the equipment cannot be allowed to depreciate to such an extent that it cannot properly perform its functions, hence, so far as operation is concerned, the plant does not have its capital wasted away. The custom on railroads of dropping equipment to lower classes of operation as it becomes depreciated (functionally chiefly) complicates the matter of making the proper depreciation charge. However, the principle that depreciation on railroads is essentially an operating expense has become quite generally accepted in this country and doubtless will be continued as a basic principle in all matters pertaining to distribution of operating expenses.

Temporary or Clearing Accounts. In railroad operation, it is frequently necessary to provide for certain kinds of work and expenditures that do not fall directly and naturally in any of the groups of operating expenses provided by the Interstate Commerce Commission classification. These are chiefly comprised of intermediate processes and finally can be properly grouped into the prescribed schedule of accounts, but they are taken care of for the time being by temporary pools called " temporary," " accommodation," " suspense," or " clearing " accounts. They are analogous to " Less and Over," " Cash Sales," " Cash Drawer " and such accounts in ordinary business. In such temporary accounts are assembled all the intermediate expenditures and any credit items are entered in a like manner. Periodically, or when the entire process is complete, these temporary accounts are closed into the appropriate account of the fixed schedule.

For example, traveling expenses in connection with buying equipment are ultimately charged to the cost of that equipment, but are taken care of temporarily by an accommodation account, Intermediate processes of blasting, steam-shovel work, etc., at ballast pits and quarries furnish other illustrations, they being finally charged to the cost of the ballast or crushed rock. The official account of the Interstate Commerce Commission, " Additions and Betterments " is in reality such a clearing account, being periodically closed into the appropriate capital account.

Classification of Railroads. The Interstate Commerce Commission classifies railroads into three groups, viz., Class I comprising those roads having total operating revenues of more than $1,000,000 annually, Class II embracing those roads having annual operating revenues between $100,000 and $1,000,000, and Class III including roads having operating revenues less than $100,000.

This classification was made in order to install a system of accounting that would be best adapted to the needs of the various roads. Most of Class III roads are very small, having from 1 to 50 miles of line. It is obvious that the same system of accounting would not be suitable for these different classes any more than the accounting methods of a large metropolitan bank would be satisfactory for a small rural bank, or vice versa. Most of the roads that have been built in the United States would have come under Classes II and III when constructed but have now been merged and grouped under large systems, so that Class I roads now represent about 90 per cent, Class II, 8 per cent and Class III roads 2 per cent of the total mileage.

Classification of Operating Expenses. Until recent years, there was no uniformity of practice in regard to operating expense accounts, but the Interstate Commerce Commission now prescribes the methods of keeping such accounts and the complete classification of items of such expense. Three different issues of these directions have been sent out, viz., 1907, 1908 and 1914. The following classification is that of the issue that went into effect July 1, 1914. The accounts of this classification "are designed to show the expenses of furnishing transportation service, including the expenses of maintaining the plant used in the service." Under the 1914 classification, there are eight groups of operating expenses, to wit:

	Account.	Per Cent of Total Op. Expenses, 1915.
I.	Maintenance of way and structures	18.0
II.	Maintenance of equipment	24.6
III.	Traffic	2.9
IV.	Transportation—Rail line	50.1
V.	Transportation—Water line	
VI.	Miscellaneous operations	
VII.	General	3.7
VIII.	Transportation for investment, (together with VI)	.7
		100.0

Table IX gives the operating expenses for the entire United States and for the three districts for the year 1915, both the total and the expenses per mile of line.

TABLE IX

SUMMARY OF OPERATING EXPENSES OF CLASS I—STEAM ROADS

FISCAL YEAR 1915

Account.	UNITED STATES.		EASTERN DISTRICT.		SOUTHERN DISTRICT.		WESTERN DISTRICT.	
	Total Amount.	Per Mile.	Total Amount.	Per Mile.	Total Amount.	Per Mile.	Total Amount.	Per Mile
Total Operating Expenses	$2,032,689,894	$8894	$928,261,738	$15,767	$309,895,015	$7323	$794,533,141	$6239
Maint of way and struc	365,968,225	1601	154,213,392	2,619	58,762,689	1389	152,992,144	1201
Maint. of equipment	498,871,462	2183	235,876,536	4,007	80,789,856	1909	182,205,070	1431
Traffic	59,464,699	260	22,565,047	383	10,966,243	259	25,933,409	204
Transportation	1,017,797,060	4453	473,874,689	8,049	146,602,307	3464	397,320,064	3120
General	74,646,461	327	31,883,072	542	11,950,944	282	30,812,445	242
All other	15,941,987	70	9,849,002	167	822,976	20	5,270,009	41
Net Operating Revenue	856,339,581	3747	354,640,101	6,023	114,094,554	2696	387,604,926	3043
Taxes	133,993,519	586	55,422,186	941	18,624,412	440	59,946,921	470
Uncollectable Revenues	640,345	3	193,151	3	114,958	3	332,236	3
Operating Income	721,705,717	3158	299,024,764	5,079	95,355,184	2253	327,325,769	2570
Operating ratio, per cent 1915		70.4		72.4		73.1		67.2
Operating ratio, per cent 1914		72.7		76.4		72.8		68.6

I. Maintenance of Way and Structures. Maintenance consists of preserving the plant in its original condition and includes not only cost of repairs, but also loss through depreciation, and loss due to fire, flood, or other casualty. In connection with maintenance, two terms, *repairs* and *renewals*, are of frequent occurrence. The former refers to replacing parts actually worn out or broken, while the latter refers to replacing parts that are partly worn with new ones in order to prevent a future breakdown.

In the following classification, where two numbers are assigned to one account, the first refers to the repairs and renewals of that account while the second refers to the depreciation.

201. *Superintendence.* This account includes the pay of officers chargeable to this account, such as executive officers, engineering staff, head carpenters and masons, and inspectors; the pay of clerks, stenographers, messengers, cooks, porters, etc.; and office and other expenses.

202, 203. *Roadway Maintenance.* Included in this account are (1) care of roadbed, (2) general cleaning of roadway, mowing weeds, removing miscellaneous debris, etc., (3) watching the roadway, extinguishing fires and patrolling, (4) bank protection, riprap, breakwaters, revetments and other devices to protect embankments, (5) train service in connection with work trains for maintenance, and (6) track changes caused by relocation of tracks.

204, 205. *Underground Power Tubes* contains the expenditures for repairs of underground power tubes and the current loss from depreciation of the same.

206, 207. *Tunnels and Subways* includes charges for repairing, ventilating and otherwise caring for such structures and the loss from depreciation of the same.

208, 209, 210, 211. *Bridges, Trestles, Culverts, and Elevated Structures.* These accounts include a number of items such as the repairs of these structures, altering, dredging and cleaning, painting and protection. The second account covers depreciation charges and the last two, similar items concerning elevated railway.

212, 213. *Ties.* These accounts cover the cost of all ties for repairs, renewals and the depreciation charges, but not expense in connection with placing the ties in the track. The cost of ties has greatly increased in the past few decades and the relative expense connected with tie renewals has greatly advanced due to this fact. Tie treatment, the use of tie plates and of screw spikes, are tending to hold this upward trend in costs in check.

214, 215. *Rails.* These accounts cover the cost of rail renewals (less salvage), and depreciation. When light rails are replaced by heavier ones, only the cost of the former are charged to this account, the remainder being charged to Additions and Betterments. Insets in rail, such as frogs, switch points and crossings are not considered rails. While the initial expense of laying rails is very great and constitutes a large portion of the initial cost, the cost of renewals averages less than one-third that of ties. Much study is now being devoted to the manufacture of rails, both as to constituents and as to processes of fabrication, with a view to prolonging their life.

216, 217. *Other Track Material* includes such items as angle bars, track fastenings, frogs, switch points, switch stands, derails, anti-creepers, etc. Interlockers and signals are not a part of track and are provided for elsewhere.

218, 219. *Ballast* includes the cost of the material delivered on the track. Where cinders are used, the cost of loading the same is charged to another account, 388. Earth placed in the middle of the track is not to be considered as ballast.

220. *Track Laying* and *Surfacing.* This account includes the cost of labor in applying ballast, ties, rails, and other track material, in aligning and surfacing track, the cost of train service in this connection, and the cost of track work in taking up and relocating tracks.

221, 222, 223, 224. *Right of Way Fences; Snow and Sand Fences.* These accounts cover all costs of repairing the structures named and the depreciation on the same.

225, 226. *Crossings and Signs.* Under these accounts come costs and charges for depreciation and highway and farm crossings, danger signals, crossing gates, and over and under crossings structures, and all track signs.

227, 228. *Station and Office Buildings.* These accounts cover costs of repairs and depreciation charges on such structures as baggage rooms, express buildings, freight houses, grain elevators, icehouses, milk stands, mail cranes, platforms, scales, stations, storehouses, telegraph offices, warehouses, etc.

229, 230. *Roadway Buildings* includes those buildings that are essentially along the line rather than at stations, e.g., carpenter shops, handcar houses, dwellings for roadway employees, etc.

231, 232. *Water Stations.* Structures coming under this account are those connected with supplying the water for the railroads, viz., pump houses, tanks, water cranes, pipe lines, dams, reservoirs, pumping machinery, etc.

233, 234. *Fuel Stations.* Fuel houses, coal pockets, fuel oil facilities, etc., come under this account.

235, 236. *Shops and Enginehouses.* Comprehended in these accounts are such structures as engine houses, repair shops, ashpits, oil houses, sand houses, transfer tables and turntables, and all others used by the carrier in repairing and preparing equipment.

237, 238. *Grain Elevators.* All structures involved in the storage or treatment of grain are grouped here. Small elevators at way stations are classed as " Station Buildings."

239, 240. *Storage Warehouses.* All structures and accompanying machinery used in storing merchandise are classed here.

241, 242. *Wharves and Docks* covers such structures located at marine, lake or river docks, dredging approaches, cutting ice, repairs of crib work, and other work connected with their proper maintenance.

243, 244. *Coal and Ore Wharves* are kept separate from the above accounts because of the peculiar nature of their construction and function.

245, 246. *Gas Producing Plants.*

247, 248. *Telegraph and Telephone Lines* cover cost of repairs to terminal and outside plant, and includes batteries, electric meters, generators, motors, engines, transformers, poles, wires, braces, insulators, etc.

249, 250. *Signal and Interlockers.* The growth of signaling and interlocking on American railways makes this an important account. It comprehends the cost of repairs to all structures used in this connection, such as signals, relays, batteries, semaphores, interlocking machinery.

251 to 264. *Power Plants.* These accounts in order include the expenses connected with maintaining power plant dams, canals, and pipe lines, power plant buildings, substation buildings, transmission systems, distributing systems, pole lines and fixtures, and underground conduits.

265, 266. *Miscellaneous Structures.*

267, 268. *Paving* include the cost of maintenance of paving where tracks are laid in paved streets.

269, 270, 271. *Roadway Machines; Small Tools and Supplies.* Hand cars, push cars, pile drivers, grading outfits, steam rollers, concrete mixers, rock crushers, ditching and dredging machines, come under the first account, and adzes, axes, crowbars, picks, mauls, tongs, wrenches, etc., under the second.

272. *Removing Snow, Ice and Sand.* Not only the cost of removing snow, ice and sand, but the cost of preventing their accumulation comes under this account.

273. *Assessments for Public Improvements.*

274. *Injuries to Persons* covers expenses caused by injuries to persons in connection with maintenance of way and structures.

275. *Insurance.*

276. *Stationery and Printing* includes the cost of materials in correspondence and reporting in connection with maintenance, e.g., paper, typewriters, calculating machines, mimeographs, postage, etc.

277. *Other Expenses.* Incidental items such as wages paid maintenance of way employees attending conferences, fees paid arbitrators of wage disputes, gratuities to persons discovering defective rails, etc., are grouped here.

278. *Maintenance of Joint Tracks, Yards, and Other Facilities, Dr.* This account is charged with the carrier's proportion of costs incurred by others in maintaining such joint facilities.

279. *Maintaining Joint Tracks, Yards, and Other Facilities, Cr.* This account includes the amounts chargeable to others as their proportions of cost incurred by the carrier in maintaining such joint facilities.

II. Maintenance of Equipment. The accounts of this group are intended to show the expenses of maintaining the carrier's equipment used in its operations, also the shop and power plant machinery. The repair accounts include the freight charges of foreign roads on machinery but not for the carrier's own transportation. The accounts must be kept so as to indicate separately the expenses assignable to sleeping-car operations, water-line operations, dining and buffet service, producing power sold, and other miscellaneous operations.

301. *Superintendence* includes the pay of the general officers as affected by this branch of the service, superintendent of motive

power, mechanical engineers, master mechanics, engineer of tests, electrical engineers, etc., the pay of clerks and attendants, office and other expenses.

302, 303. *Shop Machinery* includes repairs and depreciation of machinery in shops and engine houses.

304, 305, 306, 307. *Power Plant Machinery, Power Sub-Station Apparatus.* These accounts comprise the repairs and depreciation of all boilers, engines, generators, switchboards, transformers, etc., used for operation of trains and for furnishing heat, light and power for general purposes.

308, 309, 310. *Steam Locomotives—Repairs, Depreciation, Retirements.* These accounts cover the cost of repairs to steam locomotives and tenders, depreciation charges, and the amounts necessary to adjust the difference between the value of locomotives less salvage retired from service and the accrued depreciation.

311, 312, 313. *Other Locomotives—Repairs, Depreciation, Retirements.* These accounts are the same as for steam locomotives.

314, 315, 316. *Freight Train Cars—Repairs, Depreciation, Retirements.*

317, 318, 319. *Passenger Train Cars.—Ditto.*

320, 321, 322. *Motor Equipment of Cars—Ditto.*

323, 324, 325. *Floating Equipment—Ditto.* These accounts comprise charges similar to the above on canal boats, barges, ferry boats, lighters, launches, tugboats, and scows.

326, 327, 328. *Work Equipment—Ditto.*

329, 330, 331. *Miscellaneous Equipment—Ditto.*

332. *Injuries to Persons,* comprises expenses incident to injuries of persons that are directly connected with repairs of equipment.

333. *Insurance.*

334. *Stationery and Printing.*

335. *Other Expenses.*

336, 337. *Maintaining Joint Equipment, Dr. and Cr.* See corresponding items under Maintenance of Way and Structures.

III. **Traffic.** Traffic expenses are those incurred for advertising, soliciting and securing traffic for the carrier's lines and in preparing and distributing tariffs, governing such traffic. The function of the traffic department of a railroad is to obtain the business and the expenses of that department are listed here.

351. *Superintendence.* To this account are charged the pay of general officers connected with the traffic department, the salaries of traffic manager, freight and passenger agents, express agents, etc., the pay of clerks, and office expenses.

352. *Outside Agencies.* This account includes the pay and expenses of general, commercial, city, and district agents, and others soliciting traffic. City ticket offices, separate from station offices, are considered outside agencies.

353. *Advertising.* The pay of advertising agents, rent of their offices, donations to local associations, carnivals and other public gatherings are entered in this account. Publishing time-tables, view books, folders, putting up racks for holding same, all come under this head.

354. *Traffic Associations.* This account comprises the expenses incurred in participating in traffic associations, commercial associtions, boards of trade, etc.

355. *Fast Freight Lines.* This account covers the cost to the carrier of participation in fast freight or dispatch organizations, its proportion to the pay of officers and agents. Fast freight lines originally consisted of organizations which contracted with railroads to transport all freight that they could secure and usually furnished their own cars of special design. These organizations became co-operative agencies in which the railroads were stockholders, and later companies to which the railroads paid commissions on tonnage delivered. At the present time, the name still clings to a much changed organization, being for the most part a co-operative group of roads acting jointly for obtaining freight business.

356. *Industrial and Immigration Bureaus.* In this account are entered all expenses in connection with industrial and immigration bureaus, the cost of agricultural trains, donations to fairs, stock shows, experimental farms, etc.

357. *Insurance.*

358. *Stationery and Printing.*

359. *Other Expenses.*

IV. Transportation. Rail Line. In this group of accounts occur those expenses in connection with actual transportation or movement of persons or property over the line. It is much the largest class of expenses, constituting practically half of the total operating expenses. Transportation is the ultimate purpose for which all the departments exist.

371. *Superintendence* includes the pay of officers engaged in conducting transportation, such as the vice-president, general manager, (part time) superintendent, train master, etc., the pay of clerks, attendants, and office and other expense.

372. *Dispatching Trains* covers the pay of all dispatchers, clerks and operators solely employed in the moving of trains. This work requires a very considerable staff on large roads, the dispatcher's duty being to keep constantly in touch with all train movements on the road all the time.

373. *Station Employees.* The pay and expenses of all agents, clerks and attendants in charge of stations, wharves or piers are charged to this account, as well as all labor employed at stations.

374. *Weighing, Inspection and Demurrage Bureaus,* comprises those expenses incurred in participation in such associations as have for their purpose the inspection of weighing and billing all freight at competitive points to insure that each road lives up to its agreements with respect to its charges.

375. *Coal and Ore Wharves.* Methods peculiarly adapted to the handling of coal and ore have been developed and this kind of traffic constitutes a large portion of the business of some roads. The cost of keeping the machinery in order, the cost of tools and labor expenses are charged to this account.

376. *Station Supplies and Expenses.* Heating, lighting and other expenses are charged here, except labor, which is charged to Account 373.

377. *Yard Masters and Yard Clerks.*

378. *Yard Conductors and Brakemen.*

379. *Yard Switch and Signal Tenders.*

380, 381. *Yard Enginemen; Yard Motormen.*

382. *Fuel for Yard Locomotives.* The coal and other fuel for yard locomotives are weighed separately from that furnished for road locomotives. The cost of labor directly engaged in furnishing this fuel is also charged to this account, but the upkeep of coaling stations is charged to Account 233.

383, 384. *Yard Switching Power Produced, and Yard Switching Power Purchased,* cover cost of employees, fuel, water, repairs to machinery, and other expenses involved in producing electric power for locomotives and cars used in switching service.

385, 386, 387. *Water, Lubricants, and Other Supplies for Yard Locomotives.*

388. *Enginehouse Expenses—Yard*

389. *Yard Supplies and Expenses.*

390, 391. *Operating Joint Yards and Terminals, Dr. and Cr.* These two accounts comprehend the carrier's proportion of costs incurred by others in maintaining such joint facilities and the amounts chargeable to others as their proportions of costs incurred thus by the carrier. Railroads frequently divide such work and each does regularly certain portions, making proper charges to each other.

392, 393. *Train Enginemen, and Train Motormen.* The engineman and fireman make up the engine's crew and their pay is put into a separate account.

394. *Fuel for Train Locomotives.* Fuel is the largest single item of expense in railway operation. It includes the cost of fuel delivered and the cost of handling en route to the locomotive tender. Moreover, the price of fuel is continually increasing, the increase in price per ton between 1890 and 1914 being more than 30 per cent.

395, 396. *Train Power Produced and Train Power Purchased.* These accounts cover all fuel, labor and other expenses incurred in furnishing power for electric locomotives and cars for transportation service.

397, 398, 399. *Water, Lubricants and Other Supplies for Train Locomotives.*

400. *Enginehouse Expenses—Train.* This account comprises those expenses directly connected with the care of road locomotives and the proper proportion of the expenses common to yard and work service.

401. *Train Men* covers the pay of conductors, train auditors, baggage-men, brakemen, flagmen, porters, guards, and other train employees.

402. *Train Supplies and Expenses.* Cleaning, heating, lighting, lubricating, icing, watering, and other train expenses are entered in this account.

403. *Operating Sleeping Cars.* The cost of superintendence,

station employees, conductors, porters and maids, laundry and supplies, and other related expenses are grouped here.

404. *Signal and Interlocking Operations.* The development in recent years of this branch of service has made it a considerable item of expense. It includes expenses in connection with yard movements and movements between yards and line.

405. *Crossing Protection* covers pay of gate-keepers and signal men at highway crossings, lights, etc.

406. *Drawbridge Operating* includes all labor and supplies, repairs to machinery, etc., involved in operating movable bridges.

407. *Telegraph and Telephone Operation.* A very essential part of railway operation consists of the wire communication among all parts of the organization. The telegraph and telephone service included in this account comprises that service which relates entirely to the operation of the carrier's trains, and is separate and distinct from the commercial service.

408. *Operating Floating Equipment.* When a body of water cannot be crossed by a bridge or tunnel, it is necessary to connect the railroad on the shores by means of floating equipment—ferries, barges, lighters, etc. All expenses in connection with such transfer of traffic, including wages of crews, fuel, wages of longshoremen and stevedores, etc., are charged to this account. The water transfer at New York, the Santa Fé between Ferry Point and San Francisco, Southern Railway between Pinner's Point and Norfolk, Va., and the Southern Pacific between Oakland and San Francisco are examples.

409. *Express Service.* Express companies contract with the railroads for transporting express that the former secure for carriage. The cost of handling such express is charged to this account.

410. *Stationery and Printing.*

411. *Other Expenses.*

412, 413. *Operating Joint Tracks and Facilities—Dr. and Cr.* (See Accounts 278 and 279.)

414. *Insurance.*

415. *Clearing Wrecks.* The expenses in connection, with clearing wrecks are wages of employees, train service and other expenses.

416. *Damage to Property.* All damage to property of others caused by the carrier, except that which the carrier is trans-

porting and damage to stock on the right of way is charged to this account.

417. *Damage to Stock on Right of Way.*

418, 419. *Loss and Damage—Freight and Baggage.*

420. *Injuries to Persons.* Most of the injuries to persons caused by railroads result from accidents in transportation. The persons affected are:

1. Patrons of the road, either passengers or shippers.
2. Abutting property owners.
3. Trespassers.
4. General public at highway crossings.
5. Employees.

V. Transportation—Water Line. Several railroads have water-line transportation in addition or supplementary to their rail-line transportation, e.g., Central R. R. of N. J. at New York, the Erie R. R. between Buffalo and Milwaukee and Chicago, and the Southern Pacific between New Orleans and Galveston and New York, and between New Orleans and Havana, Cuba.

431. *Operation of Vessels,* including superintendence, wages of crews, fuels, lubrication, etc.

432. *Operation of Terminals* covers expenses in the operation of terminals devoted to water-line transportation.

433. *Incidental* covers loss and damage to property, injuries to persons, and insurance.

VI. Miscellaneous Operations. The expenses of operating such facilities as hotels, restaurants, power plants, cold storage plants, cotton compress plants, wood preserving, ice supply, etc., when not distinct and separate from the facilities used in transportation are charged here.

441. *Dining and Buffet Service.*

442. *Hotels and Restaurants.*

443. *Train Elevators.*

444. *Stock Yards.*

445. *Producing Power Sold.* Sometimes railways sell power from their plants, and this account is intended to provide for the expense of furnishing such power.

446. *Other Miscellaneous Operations,* such as ice, cold storage, cotton compress, wood-preserving plants.

VII. General. This group of expenses covers the salaries of general officers, law expenses, pensions, valuation expenses, and other expenses that are not chargeable to specific operations, but belong to all departments to a greater or less degree.

451. *Salaries and Expenses of General Officers.* The chairman of the board of directors, the president, secretary, treasurer, comptroller, auditor, and other general officers are chargeable to this account.

452. *Salaries and Expenses of Clerks and Attendants.*

453. *General Office Supplies and Expenses.*

454. *Law Expenses.* The general legal staff belongs to the entire road and naturally is chargeable to general expenses. The salaries of the general counsel, general solicitor, attorneys and the expense of general litigation are included in this account.

455. *Insurance.*

456. *Relief Department Expenses.*

457. *Pensions.*

458. *Stationary and Printing.*

459. *Valuation Expenses.* The Interstate Commerce Act requires co-operation on the part of carriers, and this entails a very large expense. The various state commissions also require many reports and statements, the preparation of which involves much cost. All such expenses are charged to this account.

460. *Other Expenses.*

461, 462. *Joint Facilities—Dr. and Cr.*

VIII. **Transportation for Investment—Cr.** This group of expenses provides for the transportation of persons or materials engaged in construction and fair allowances for such transportation are charged thereto. Amounts credited to this account are concurrently charged to the appropriate property investment accounts.

Table X shows the per cent of the total operating expenses for each item or account for Class I roads. Table XI shows similar items for Class II roads for the year 1914.*

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* N.B.—Owing to the incompleteness of the statistics under the 1914 classification, Tables X and XI are given for the fiscal year 1914 and represent the 1908 classification.

TABLE X

ANALYSIS OF OPERATING EXPENSES FOR THE YEAR 1914. CLASS I ROADS

Account.	PER CENT OF TOTAL EXPENSES.			
	Eastern District.	Southern District.	Western District.	United States.
I. *Maintenance of Way and Structures:*				
1. Superintendence	.852	.929	1.148	.977
2. Ballast	.325	.465	.285	.332
3. Ties	2.717	3.135	3.480	3.074
4. Rails	.979	.913	.734	.875
5. Other track material	1.098	.933	.875	.987
6. Roadway and track	5.802	6.606	8.203	6.846
7. Removal of snow, sand, etc	.413	.051	.178	.266
8. Tunnels	.039	.058	.064	.051
9. Bridges, trestles, etc.	1.416	2.209	1.792	1.685
10. Over and under crossings	.098	.052	.047	.071
11. Grade crossings, etc	.302	.243	.397	.329
12. Snow and sand fences, etc.	.003	.001	.051	.021
13. Signals and interlocking plant	.840	.295	.295	.546
14. Telegraph and telephone lines	.254	.135	.206	.217
15. Electric power transmission	.071	......	.010	.037
16. Buildings, fixtures, and grounds.	1.750	1.609	1.802	1.747
17. Docks and wharves	.160	.163	.137	.152
18. Roadway tools and supplies	.190	.258	.317	.249
19. Injuries to persons	.096	.150	.198	.144
20. Stationery and printing	.036	.037	.039	.037
21. Other expenses	.013	.010	.008	.011
22. Maint. joint tracks, etc., Dr.	.894	.592	.701	.773
23. Maint. joint tracks, etc., Cr.	*.641*	*.431*	*.519*	*.561*
Total, M. of W. and S.	17.707	18.413	20.448	18.866
II. *Maintenance of Equipment:*				
24. Superintendence	.704	.713	.701	.704
25. Steam locomotives, repairs	8.155	8.171	8.223	8.183
26. Steam locomotives, renewals	.172	.162	.073	.132
27. Steam locomotives, depreciation	1.092	.974	.972	1.027
28. Electric locomotives, repairs	.073	......	.006	.036
29. Electric locomotives, renewals	......	......	......	......
30. Electric locomotives, deprec'n	.022	......	.005	.012
31. Passenger cars, repairs	1.562	1.498	1.487	1.523
32. Passenger cars, renewals	.081	.037	.018	.050
33. Passenger cars, depreciation	.281	.252	.337	.298
34. Freight cars, repairs	9.093	10.222	7.101	8.510
35. Freight cars, renewals	.854	.570	.298	.597
36. Freight cars, depreciation	2.015	2.490	1.789	2.004
37. Electric equipment of cars, rep.	.024	......	.007	.014
38. Elec. equipment of cars, renewals	......	......	......	......

TABLE X—*Continued*

Account.	PER CENT OF TOTAL EXPENSES.			
	Eastern District.	Southern District.	Western District.	United States.
II. *Maintenance of Equipment* (*con*).				
39. Elec. equipment of cars, deprec.	.014	......	.001	.007
40. Floating equipment, repairs...	.054	.024	.041	.044
41. Floating equipment, renewals...	.002	.005	.003	.003
42. Floating equipment, deprec'n...	.021	.005	.022	.019
43. Work equipment, repairs.......	.186	.204	.289	.228
44. Work equipment, renewals.....	.047	.027	.032	.038
45. Work equipment, depreciation. .	.054	.077	.109	.079
46. Shop machinery and tools......	.589	.530	.500	.546
47. Power plant equipment........	.037	.....	.004	.018
48. Injuries to persons............	.089	.110	.152	.117
49. Stationery and printing........	.061	.056	.044	.054
50. Other expenses...............	.036	.020	.014	.025
51. Maint. joint eq. at ter., Dr.....	.097	.112	.064	.087
52. Maint. joint eq. at ter., Cr.....	*.060*	*.043*	*.024*	*.044*
Total Maint. of equipment...	25.355	27.216	22.268	24.311
III. *Traffic Expenses:*				
53. Superintendence..............	.688	.938	.787	.765
54. Outside agencies..............	.810	1.251	1.483	1.137
55. Advertising..................	.268	.300	.547	.379
56. Traffic associations...........	.064	.095	.069	.071
57. Fast freight lines.............	.265	.199	.002	.154
58. Industrial and immig. b's......	.030	.165	.110	.082
59. Stationery and printing........	.333	.398	.274	.320
60. Other expenses...............	.004	.001	.009	.006
Total Traffic Expenses.......	2.462	3.347	3.281	2.914
IV. *Transportation Expenses:*				
61. Superintendence..............	1.383	1.178	1.136	1.256
62. Dispatching trains............	.948	.946	.679	.845
63. Station employees.............	7.187	7.034	6.462	6.886
64. Weighing and car serv. assns. . .	.051	.203	.160	.117
65. Coal and ore docks...........	.265	.034	.127	.176
66. Sta. supplies and expenses.....	.642	.476	.534	.574
67. Yard masters and their clerks. .	.999	.897	.651	.850
68. Yard conductors and brakemen	3.441	2.413	2.268	2.830
69. Yard switch and sig. tenders....	.310	.112	.138	.213
70. Yard supplies and expenses....	.109	.075	.043	.079
71. Yard enginemen..............	1.961	1.461	1.320	1.637
72. Enginehouse expenses—yard...	.544	.419	.543	.524
73. Fuel for yard locomotives......	1.717	1.181	1.553	1.570
74. Water for yard locomotives....	.121	.084	.106	.109
75. Lubricants for yard locomotives	.034	.027	.026	.030
76. Other supplies for yard locos...	.041	.033	.028	.035

TABLE X—*Continued*

Account.	Per Cent of Total Expenses.			
	Eastern District.	Southern District.	Western District.	United States.
IV. *Transportation Expenses (cont.)*				
77. Oper. joint yds. and ter., Dr.	1.399	1.426	1.214	1.332
78. Oper. joint yds. and ter., Cr.	*.901*	*.844*	*.641*	*.793*
79. Motormen	.081	......	.029	.048
80. Road enginemen	5.804	6.293	5.975	5.947
81. Enginehouse expenses—road	1.687	1.607	1.829	1.729
82. Fuel for road locomotives	8.650	8.232	10.847	9.423
83. Water for road locomotives	.572	.561	.693	.617
84. Lubricants for road locos	.171	.185	.177	.175
85. Other supplies for road locos	.207	.191	.171	.191
86. Operating power plants	.110	......	.020	.058
87. Purchased power	.089	......	.019	.048
88. Road trainmen	6.397	6.577	6.370	6.415
89. Train supplies and expenses	1.741	1.661	2.041	1.843
90. Interlockers and block sig. op.	.824	.201	.316	.532
91. Crossing flagmen and gatemen	.532	.174	.229	.360
92. Drawbridge operation	.055	.052	.039	.049
93. Clearing wrecks	.270	.320	.243	.267
94. Telegraph and telephone oper.	.319	.262	.283	.296
95. Operating floating equipment	.142	.054	.185	.145
96. Express service	.005	......	......	.002
97. Stationery and printing	.481	.449	.347	.425
98. Other expenses	.171	.091	.094	.129
99. Loss and damage—freight	1.316	1.718	1.776	1.555
100. Loss and damage—baggage	.013	.018	.014	.014
101. Damage to property	.166	.242	.234	.204
102. Damage to stock on R. of W.	.034	.463	.264	.190
103. Injuries to persons	.906	1.659	1.541	1.223
104. Op. jt. tracks and fac., Dr	.327	.164	.282	.284
105. Op. jt. tracks and fac., Cr.	*.289*	*.185*	*.249*	*.257*
Total Transportation Exp.	51.032	48.144	50.026	50.192
V. *General Expenses:*				
106. Salaries of general officers	.414	.494	.556	.481
107. Salaries and expenses of clerks	1.451	1.460	1.685	1.542
108. General office supplies and exp.	.178	.156	.195	.182
109. Law expenses	.442	.810	.610	.564
110. Insurance	.310	.365	.393	.350
111. Relief department expenses	.058	.015	.012	.034
112. Pensions	.255	.093	.111	.174
113. Stationery and printing	.148	.172	.168	.159
113½. Valuation expenses	.045	.119	.100	.078
114. Other expenses	.111	.166	.117	.122
115. Gen. admin. joint fac., Dr	.052	.038	.042	.046
116. Gen. admin. joint fac., Cr.	*.020*	*.008*	*.012*	*.015*
Total General Expenses	3.444	3.880	3.977	3.717

TABLE XI

ANALYSIS OF OPERATING EXPENSES FOR THE YEAR 1914 CLASS II ROADS

Account.	PER CENT OF TOTAL EXPENSES.			
	Eastern District.	Southern District.	Western District.	United States.
I. *Maintenance of Way and Structures:*				
1. Superintendence	1.187	1.214	1.342	1.268
2. Maint. of roadway and track	17.868	18.159	20.443	19.182
3. Maint. of track structures	3.902	3.948	4.029	3.972
4. Maint. bldgs., docks, wharves	1.585	1.096	1.588	1.500
5. Injuries to persons	.049	.127	.141	.108
6. Other m. of w. and s. expenses	.289	.442	.738	.536
7. Maint. joint facilities, Dr.	.631	.387	.822	.681
8. Maint. joint facilities, Cr.	*3.047*	*.528*	*.788*	*1.494*
Total Maint. W. and S. Exp.	22.464	2.845	28.315	25.753
II. *Maintenance of Equipment:*				
9. Superintendence	.825	1.224	.985	.974
10. Locomotives, repairs	5.940	6.097	6.474	6.230
11. Cars, repairs	9.513	7.290	5.862	7.331
12. Floating equipment, repairs	.012	.035	.052	.036
13. Work equipment, repairs	.103	.182	.267	.197
14. Equipment, renewals	.330	.683	.516	.483
15. Equipment, depreciation	4.688	2.602	3.602	3.786
16. Injuries to persons	.036	.049	.097	.068
17. Other maint. of equip. exp	.635	.663	.618	.631
18. Maint. joint equip. at ter., Dr.	.010	.049	.051	.037
19. Maint. joint equip at ter., Cr.	*.022*	*.002*	*.105*	*.059*
Total Maint. Equip. of Exp.	22.070	18.872	18.419	19.714
III. *Traffic Expenses:*				
20. Traffic expenses	1.835	3.193	2.328	2.317
IV. *Transportation Expenses:*				
21. Sup. and dispatching trains	2.306	2.172	2.010	2.138
22. Station service	7.997	6.721	7.119	7.340
23. Yard enginemen	1.217	.556	.825	.908
24. Other yard employees	2.288	.752	1.515	1.637
25. Fuel for yard locomotives	1.473	.800	1.371	1.303
26. All other yard expenses	.527	.185	.430	.419
27. Op. joint yards and term., Dr.	1.028	1.820	1.226	1.265
28. Op. joint yards and term., Cr.	*.748*	*.200*	*1.401*	*.971*
29. Road enginemen and motormen	6.282	6.055	5.684	5.949
30. Fuel for road locomotives	10.447	11.125	11.731	11.196
31. Other road loco. sup. and exp.	3.296	2.216	3.039	2.979

TABLE XI—*Continued*

Account.	PER CENT OF TOTAL EXPENSES.			
	Eastern District.	Southern District.	Western District.	United States.
IV—*Transportation Expenses—Con.*				
32. Road trainmen	7.574	6.305	6.127	6.640
33. Train supplies and expenses	1.137	.845	1.196	1.114
34. Injuries to persons	1.093	2.037	.746	1.091
35. Loss and damage	.550	.858	.638	.648
36. Other casualties	.433	1.046	.691	.668
37. All other transportation exp.	2.493	1.208	1.049	1.557
38. Oper. jt. tracks and facil., Dr.	.557	.262	.490	.472
39. Oper. jt. tracks and facil., Cr.	*1.594*	*.192*	*.379*	*.750*
Total Transportation Exp.	48.356	44.571	44.107	45.603
V. *General Expenses:*				
40. Administration	4.643	6.920	5.626	5.529
41. Insurance	.457	.817	.770	.694
42. Other general expenses	.470	.717	.513	.535
43. Gen. admin. jt. tracks, etc., Dr.	.003	.077	.040	.034
44. Gen. admin. jt. tracks, etc., Cr.	*.298*	*.012*	*.118*	*.159*
Total General Expenses	5.275	8.519	6.831	6.613

Traffic Unit of Operating Expenses. In analyzing operating expenses of railroads, it is necessary to use some unit of operation or traffic as a basis for such analysis. There is no elemental traffic unit that may be chosen so that operating expenses vary directly as the number of such units, hence, one must be selected that most nearly answers the requirements. The train-mile has been generally used as such a unit of expense and on the whole is perhaps the most satisfactory of those proposed, although total operating expenses do not vary in direct proportion to the train miles by any means, and in fact, probably none of the items vary directly as the train mileage. The train is essentially the unit of operation, but the expenses incident to its movement do not vary with the mileage. The car-mile and the ton-mile have been used to a limited extent for particular purposes, but the train-mile is almost universally adopted as the general unit of expense.

So far as maintenance of way and structures is concerned, a number of units have been proposed and used to a greater or less extent, a few of which will be mentioned.

The *train-mile* has been most generally used in the past, but it is illogical because of its variableness in weight, speed, condition of equipment, etc.

The *engine-mile* has been proposed and used to a certain extent in recent years, being the unit contained in the "Oklahoma Formula" (See Chapter VII). The weight of the engine is of course a measure of the train load and of the speed that can be maintained over the division, but it is doubtful if the scheme will have general acceptance. This unit would result in assigning a larger proportion of the wear to passenger traffic.

The *gross ton-mile* has been used to a considerable extent, being generally favored by the various state commissions, and it seems to be more logically supported by the evidence available than perhaps any of the others. It combines simplicity with at least a reasonable reliability and bids fair to be the one most generally accepted in the future.

The *equivalent ton-mile* has been proposed in which the tonnage of all traffic and of the locomotives is rated in terms of a common unit. The ratios proposed by the Committee of the Am. Ry. Eng. Assn.,* but not accepted are,

Freight ton-mile	1
Passenger ton-mile	~~2~~ 1
Freight locomotive ton-mile	2
Passenger locomotive ton-mile	~~2~~ 3

While an equivalent tonnage rating may be the most desirable, the ratios would need to be determined by very careful investigation and study. In the celebrated Buel vs. C. M. & St. P. Ry. case before the Wisconsin Railroad Commission, the following arguments were submitted to show that passenger traffic does not do greater harm per ton to way and structures than does freight traffic:

1. Those roads like the Lehigh Valley, Lackawanna, Wheeling and Lake Erie, Duluth and Iron Range, Missabe and Northern,

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* Proc., Vol. XIV, p. 580.

which are essentially freight roads, have as high maintenance costs per train-mile as those roads that carry largely passenger traffic, such as the New York Central and Hudson River, the New York, New Haven and Hartford.

2. The wear of wheel tread is a measure of the wear of rails and it is found that the wear on drivers is not less rapid on freight than on passenger locomotives and the wear on drivers does not increase with the speed.

Everything considered, it seems that the gross ton-mile is probably the most rational traffic unit of wear on way and structures, and the train-mile the most acceptable general unit of operating expenses.

Analysis of Maintenance of Way and Structures Expenses. The design of a railway location depends chiefly upon main track conditions so far as maintenance of way and structures expenses are concerned. These expenses are dependent mainly upon two factors, viz., time and traffic. Rusting and rotting are time processes and are fairly constant, while wear is the result of traffic. On the basis of the assumed relations mentioned in the preceding paragraph, the Committee of the Am. Ry. Eng. Assn. plotted all data available for the chief accounts of this group, from which average curves give the following formulas for costs in dollars per mile for main track only:

Superintendence	18+8M
Rail	11M
Ties	....
Other track material	10M
Roadway and Track	200+49M
Buildings	10+24M
Roadway Tools	5+2M

where M equals million equivalent ton-miles of traffic. The equivalent ton-mileage of locomotives is about 20 to 30 per cent of the total train ton-mileage for freight traffic and about 40 to 50 per cent for passenger.

With regard to the relative cost of sidings and main track, the above Committee reports the following conclusions from its studies as the ratio between the cost of maintaining one mile of sidings to that of one mile of main track:

	Ratio.
Superintendence	1 : 3
Ballast	1 : 4
Ties	1 : 2
Rails	1 : 4
Other track material	1 : 1
Roadway and track	1 : 3
Roadway tools, etc.	1 : 3

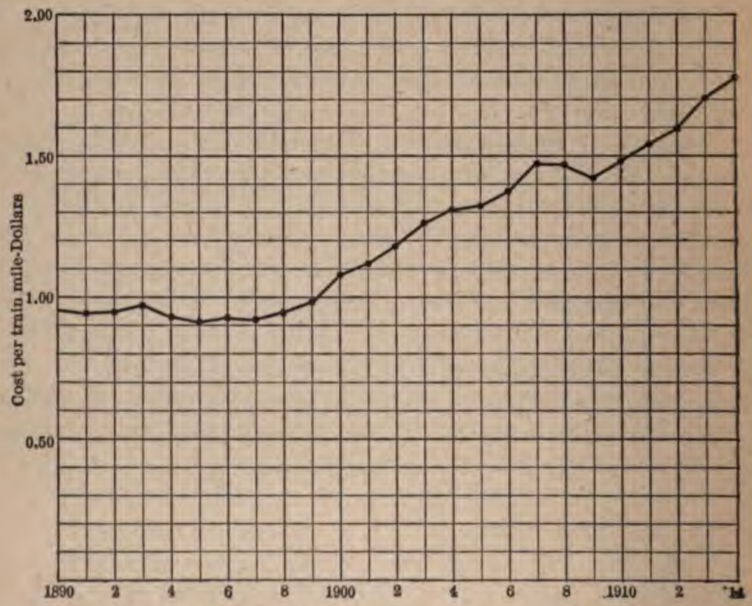

Fig. 7.—Operating Expenses per Train-Mile in the United States

It is stated that the above ratios are not valid for territory that is densely built up with mines or manufactures, where the mileage of side tracks is exceedingly large.

Operating Expenses per Train-Mile. The tendency of operating expenses has been to increase per train-mile because of the higher price of labor, materials, fuel and other items. The reports of the Interstate Commerce Commission give data from which the curve of Fig. 7 was plotted. However, a study of statistics shows that the cost per train-mile is fairly uniform for different roads of the same class in the various parts of the country. The operating expenses for all roads of the United States for

1914 was $1.769 per train-mile. The operating expenses for the following Class I railroads indicate that the average is fairly close to the amount for any road having the ordinary traffic:

N. Y. C. & H. R.	$1.81
C., B. & Q.	1.74
Penna	2.24
C. & N. W.	1.53
Southern	1.44
C., R. I. & P.	1.45
Mo. Pac	1.89
A., T. &. S. F.	1.72
Ill. Cent	1.59
C., M. & St. P.	1.58

Small roads vary considerably from these averages, being somewhat less generally and lacking in uniformity, as shown by the following examples of Class II roads:

Buffalo & Susquehanna	$1.63
Chic. & Ill. Midland	2.07
Dayton & Union	.81
Zanesville & Western	2.51
Ga. & Fla.	1.04
Tacoma Eastern	2.23
Wichita Valley	1.32
Texas & Gulf	1.87
San Joaquin	3.51

The following figures show the variation in operating expenses in the different parts of the United States for the different classes of railroads for the year 1912:

	Class I.	Class II.	Class III.
Eastern district	$1.93	$1.37	$1.07
Southern district	1.58	1.14	1.04
Western district	1.71	1.67	1.56

In general, operating expenses are higher on eastern and western roads than on southern, due chiefly to high class of labor employed on the former.

Operating Expenses per Ton-Mile. Complete data are not available for determining the cost per ton-mile of both freight and passenger traffic and even less information is available concerning the cost of each per ton-mile. However, assuming the average weight of a passenger coach as 70 tons, the average cost per ton-mile in the United States has been as follows for the gross weight of trains:

	Cents per ton-mile
1913	.26
1912	.26
1911	.26
1910	.25

Approximately one-fourth of this total ton-mileage is passenger and three-fourths freight. The data at hand point to the fact that the cost per ton-mile is fairly constant regardless of increase in prices and of general operating expenses. This is chiefly due probably to heavier train load and economies effected in operation.

Taxes. While taxes are not strictly included in operating expenses, they are commonly listed with them. The basis on which taxes are assessed differs in the various states, the par value of stocks and bonds being used in some cases and the total capital stock in others, and still other assessment valuations in other states. They vary from $101 in South Dakota to $2047 per mile in New Jersey, and constitute approximately 4.2 per cent of earnings. The average rate of assessment is approximately 74 cents per $100.

Taxes are assessed in most states on the value of real and personal property chiefly, although Wyoming is the only state where such is the only basis of taxation. The following table indicates the practice in most states where taxes are not levied chiefly on real or personal property,

TABLE XII

BASIS OF TAXATION OF RAILWAYS

State.	Real and Personal Prop.	Stocks and Bonds.	Earnings.	Traffic.	Miscellaneous.
Connecticut	7.3	91.8	....	....	0.9
Delaware	30.5	0.8	....	68.2	0.5
Illinois	77.2	....	21.6	....	1.2
Kentucky	73.0	23.5	....	....	3.5
Maine	16.3	....	81.8	....	1.9
Maryland	27.0	....	59.5	....	13.5
Massachusetts	46.6	49.1	0.4	....	3.9
Minnesota	0.9	....	98.6	....	0.5
Mississippi	89.3	....	10.7	....	0.1
New Jersey	79.3	12.1	6.2	0.6	1.8
Ohio	69.8	....	27.7	....	3.3
Pennsylvania	12.1	68.0	15.9	....	3.9
Texas	80.6	19.0	0.2	....	0.1
Vermont	2.3	0.7	95.0	....	2.0
Virginia	73.1	0.1	26.7	....	0.1
Washington	87.9	....	....	12.1	....
Dist. Columbia	74.8	....	....	....	25.2

CHAPTER VII

RAILWAY RATES AND REVENUES

Basis of Rates. Two different principles underlie the making of the rates that are charged by any corporation, viz., (1) the commercial and (2) the scientific, so called. Commercial rates are dependent in a small degree on the cost of production and upon the value of the service to the patrons, the whole being modified and finally determined chiefly by competition in one form or another. Commercial fixing of rates applies in practically all cases where the service is competitive. The scientific method of fixing rates, as it is commonly designated, is applicable where the service is monopolistic rather than competitive. It is based on the idea that the rate should be such as to pay operating expenses, all fixed and overhead charges, and dividends on capital stock. The method is applicable in determining monopolistic rates, such as water, gas, power, etc., in cities, but cannot be directly applied in determining railroad rates, although some have contended that it can be so applied.

Railways, as has been seen, are *quasi* public or semi-public corporations. To the extent that they are private corporations they may fix rates with due regard to the interests of the stockholders, but in so far as they are public corporations, their primary aim is to serve the public rather than the stockholders. Railway rates have grown up to a system from entirely unrelated and disconnected operations, and to understand the rate structure of the United States it is necessary to study the history of rate making as well as the existing status, but to do so would be entirely beyond the province of these brief paragraphs. However, a locating engineer, in order to design an economical transportation plant that will produce maximum revenues, should be familiar with the essential principles of rate making and an extended study in this direction would be profitable. In general, it may be stated, rates between controlling competitive points are now established and new rates are determined in accordance with these. The existing rates are not the result of any logical determination, but represent the product of compromise and competition and legislative enactment to a considerable extent.

Relation to Commerce. In the complex organization of society, transportation charges enter very largely into the price of almost every commodity used, and for this reason also the interests of railroads are very closely related to those of the public. The extent to which freight charges affect retail prices depends, of course, upon the nature of the commodity, varying from perhaps 30 per cent in the case of certain perishable commodities to less than 1 per cent for those items which do not require special care in handling.

The railroads facilitate commerce by affording a method of transporting commodities at a low cost. Most of the freight traffic of railroads arises from commerce, that is, the conveyance of commodities from one place to another is accompanied by a transfer of ownership, the consignor usually being a vendor and the consignee a vendee. By extending the market for selling and by enlarging the opportunities for buying, railroads contribute to the commercial activities of society. The marked impetus given to agricultural pursuits of the central states by the completion of the Erie Canal and by the building of railroad outlets to the Atlantic Coast are illustrations of this fact.

Reasonable Rates. The Interstate Commerce Act prescribes that rates must be reasonable, which at best is a rather indefinite requirement. However, a rate would hardly be held to be reasonable or logical unless it was based, in a general way at least, upon (*a*) the cost of the service and (*b*) the value of the service to the patron.

The cost of the service has been discussed somewhat at length in Chapter VI, and it may be summarized here by stating that it depends upon (*a*) the proportionate part of the operating expenses chargeable to that service and (*b*) the proportionate share of fixed charges. Rates should meet these costs, which is another way of saying that they should bring a fair return upon the capital invested after paying operating expenses. In Chapter IV, the methods of arriving at a fair valuation of railway property are discussed and in Chapter VI the cost of operation is rather briefly outlined. It is entirely impossible to ascertain the cost of transporting any particular commodity.

The value of the service, also, is extremely variable. Where transportation is accompanied by a sale, the value of the transportation is equal to the enhanced value of the commodity, although this is not easily determined. In any case, the added value in a fairly definite way limits the rate. In general, *charging what the traffic will bear*, as is the custom, is applying the principle of value of service rendered. Revenue must be obtained where *revenue is to be had*. Different grades of goods must necessarily pay different rates for the same transportation service because of their difference in ability to pay. Cheap goods will not justify as high rates as more expensive articles; cheap bulky articles can be obtained for transportation only at low rates. Coal, ore, grain, lumber, etc., cannot bear as high transportation charges as dry goods, fine hardware, porcelain ware, musical instruments, etc. From the railroad's point of view any traffic that yields a profit above the actual cost of transportation is desirable, even though if all traffic were conducted at similar rates ruin would result. From these considerations, the following deductions may be made:

(1) Cheap and bulky articles pay little, but necessarily something above the actual cost of moving them. Such articles do not pay their proportionate share of fixed charges.

(2) Commodities of medium bulk and value pay the expense of their moving and their proportional share of capital charges but nothing more.

(3) Articles of small bulk and high value pay their share of operating and fixed charges and yield a high profit in addition.

(4) Short-distance rates are, in general, somewhat higher in proportion than long-distance rates.

If traffic is charged more than the value of the service, there will be no shipments; if all the service is worth, there will be no inducement to make shipments; but if less, shipments will be made.

Distribution of Operating Expense to Different Classes of Service. In attempting to ascertain the cost of any particular branch of railroad service, it is necessary to apportion the cost of operation and of fixed charges properly belonging to that branch of service. Under the present accounting system required by the Interstate Commerce Commission, the expenses pertaining to any branch are kept separate so far as practicable, approximately three-fourths of the total expenses being distinctly separated in this manner. The first group of operating expenses, Maintenance of Way and Structures, however, is composed of items that, with the information at present available, are almost inseparable with respect to the branches of service. On the other hand, the other groups of expenses are differentiated with a fair degree of accuracy, particularly as regards the two main branches of service, viz., freight and passenger. The Railroad Commission of Wisconsin was one of the first to attempt a separation of the accounts with a view to ascertaining the actual cost of each branch of the service. In the celebrated Buell vs. C. M. & St. P. Ry., the operating expenses, after an exhaustive study, were allocated as follows for Wisconsin:

	Freight, Per Cent.	Passenger, Per Cent.
Maintenance of Way and Structures.	8.38	8.34
Maintenance of Equipment.........	13.06	3.90
Conducting Transportation.........	40.30	16.66
General Expenses..................	6.26	3.10
Total........................	68.00	32.00

The chief contention, as stated above, gathers around the first group of expenses. The fundamental conception is to distribute maintenance of way expenses according to the use of the track. Immediately two questions arise, the second being dependent upon the first. In the first place, what are the relative effects of freight and passenger traffic and, in the second, what shall be taken as the traffic unit of use?

The Pennsylvania Railroad was one of the first to begin the study of this perplexing question and that company worked out a scheme based on the revenue train-mile as the unit of use, except for electric power transmission and docks and wharves. The objection to this plan is that it rests on the assumption that passenger trains and freight trains cause the same damage to way and structures per train-mile. Maintenance of equipment was allocated in the Pennsylvania scheme according to observed facts so far as possible and otherwise according to revenue train mileage.

The Oklahoma Railroad Commission in 1914 made a study of the division of maintenance of way expenses on the assumption that a considerable portion of such expenses varied with the traffic and would be discernible by observation. Four bases of division were tried, viz., (1) a revenue train-mile basis, (2) a speed ton-mile basis, using the average speed between stations, which in effect made the ton-mile per hour the unit of use, (3) an engine ton-mileage basis, the weight of the engine including the weight of the tender loaded, (4) the basis of assignable line expenses, such as repairs to equipment, road enginemen's wages, etc. This last method was called the Cost Accounting Method. After considerable investigation, the Commission gave up all four of these methods and adopted a division of expense on the basis of engine-mileage. The expenses in connection with maintenance of equipment that are not directly assignable are apportioned according to the Cost Accounting Method or according to the miles run. Transportation expenses are assigned directly as far as possible and common expenses are apportioned according to the assignable expenses, i.e., according to the Cost Accounting Method. This scheme is commonly known as the "Oklahoma Formula," * and its essential features are that the unassignable maintenance expenses are apportioned according to the engine mileage and other unassignable expenses in general are allocated in proportion to the items directly assignable. The "Oklahoma Formula" attempts to separate the expenses of freight and passenger service, line and terminal service, and interstate and intrastate facilities. Its present status, however, does not warrant a more complete exposition at this time.

Another method of allocating maintenance of way expenses, and one that is generally favored by the state commissions, is assigning such expenses according to gross ton-mileage. Many claim that the damage done to track and structures is essentially in proportion to the tonnage and that the effect is about the same for a ton of freight locomotive, passenger locomotive, freight car or passenger coach. Some experiments made by the author seem to support this view.† The inferior condition of wheels and equipment generally in freight traffic appears to counterbalance any effects due to high speed of passenger trains. The special committee of the American Railway Engineering Associa-

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* *Railway Age Gazette*, July 3, 16 and 24, 1914.

† *Railway Age Gazette* July 16, 1915.

tion on Stresses in Track reported in 1916 that their experiments indicated an increase in track stresses with the speed at the rate of about 0.75 per cent for each mile per hour above 5 miles per hour.

Obviously not all maintenance of way and structures expenses are chargeable in proportion to units of traffic. A large percentage including those involved in keeping up grounds, slopes, right of way fences, signs, etc., is independent of the traffic carried. In fact, of the entire account of maintenance of way and structures constituting 18.87 per cent of the total in 1914, only a few of the items are affected at all by the traffic and some of these but slightly, as indicated in Table XIII.

TABLE XIII

PROPORTION OF M. OF W. AND STRUCT. AFFECTED BY TRAFFIC

Item.	Av. Per cent, 1914.	Proportion Affected.	Per cent Affected by Traffic.
Ballast	.33	.75	.24
Ties	3.07	.50	1.53
Rails	.88	.90	.72
Other track mat.	.99	.90	.90
Roadway and track	6.85	.50	3.42
Bridges, etc.	1.69	.50	.85
Injuries to persons	.14	1.00	.14
			7.80

These results would indicate that 7.80/18.87 or 41.5 per cent of maintenance of way and structures expenses varies with the traffic. For these expenses that vary with the traffic, the gross ton-mile is perhaps the most satisfactory unit of traffic for the allocation of expense between the classes of service.

Freight Classifications. Owing to the fact that some goods cost more to handle than others and the value of the service rendered is greater in some instances than in others, it is convenient and almost a matter of necessity to classify articles in order appropriately to determine the rates to be charged. Obviously, the whole question of rates is inseparably bound up with the classification of commodities; in fact, a large proportion of the complaints charging discrimination made by communities hinge on the question of classification. Originally the classifications of freight were made by the railroads individually as were the tariffs, but such an arrangement led to endless confusion. While the tariffs are still made in the main by the railroads, the classifications are made by co-operative bodies known as "Classification Committees," a Committee representing the different railroads in the territory where that classification prevails. There are three general classification committees, each prescribing for one of three classification territories. These classification territories are known as the Official, the Southern and the Western. The Official Classification Territory embraces that region lying east of Chicago and North of the Ohio and Potomac rivers, the Southern, the remaining portion of the country east of the Mississippi and south of the Ohio, and the Western, the remainder of the United States. The Official Territory includes three minor regional classifications, viz., New England, Trunk Line (roughly bounded by the Hudson, Allegheny, St. Lawrence, Kanawha and James rivers), and Central Traffic Territory (roughly bounded by Lakes Michigan, Huron, Erie, and the Illinois, Ohio and Allegheny rivers). The Western Classification comprises the Trans-Mississippi, the Trans-Missouri (extending to the Rocky Mountains), and the Pacific Slope Territory.

In Official Classification Territory, there are six classes of freight, those commodities taking the highest rate being Class I and those of the lowest rate constituting the sixth class. In Western Classification, there are five numbered classes, 1 to 5, and five lettered classes, A to E. The Southern Classification has six numbered classes, 1 to 6, and eight lettered classes, A to H. The lettered classes in both cases include the low-grade freight. Efforts have been made to secure a uniform classification for the whole country, but without success. The difference in the service rendered in the sparsely settled regions of the West and in the populous districts of the East, along with other wide variations of conditions, would seem to justify the present arrangement.

Joint Through Rates. A joint tariff rate must show on its face what carriers unite in establishing such joint rate. It has been held by the Interstate Commerce Commission that where freight passes over a continuous route operated by more than one company on which no tariff rates or charges have been established, the rate is the sum of the established local rates of the several companies operating such a continuous line. It has also been held that while competing railways may maintain the same rate between terminal points, a higher rate may be maintained to a branch line point off the direct through line without unjust discrimination.*

In a division of a through rate between carriers, it has been held that a single freight charge between points need not be divided on a mileage basis merely, for many of the considerations which affect the fixed rate are peculiar to one carrier and not to the other. As a matter of fact, through rates are usually subject to agreement between carriers making up such through lines, and one of the features of such rates usually is that the carrier receiving the freight pays the charges of the carrier that delivers it to its destination, the latter holding the essential control of the situation. In practice, it is customary to formulate through rates over long distances with reference to certain large shipping points between which the rate is competitive. For example, east and west traffic rates are made between East coast cities and Chicago and St. Louis, and between these latter cities and "Missouri River points," i.e., Kansas City and Omaha, and between Missouri River points and Rocky Mountain towns and the Pacific Coast.

Switching. Usually cars are transferred from one road to another over an *interchange track* which may be owned by one road, or both roads or by a separate corporation. The movement of the cars is done by the locomotives of these roads under certain working agreements, the road doing the switching being allowed a compensation for such service. The compensation is arranged for chiefly by reciprocal switching, but sometimes railroads charge each other full switching rates. In certain cities like Chicago, Kansas City, Peoria, and others, a special terminal company attends to the interchange of traffic. The charge for such switching, however done, varies usually from $2.00 to $3.00 per car, but in some instances it runs as high as $6.00 or $7.00.

The charge for transportation made to the shipper must be adjusted, of course, to cover all switching charges.

Industrial Tracks. Large manufacturing concerns require special sidings and spurs for accommodating their business. The amount of switching done by the railway depends upon the agreement in each particular case, much work of this sort having having been done gratis in the past years. However, the action of the Interstate Commerce Commission tends to compel a charge to be made for this service in proportion to the value thereof. In the cases brought by the Solvay Process Company and the General Electric Company, the Interstate Commerce Commission held that the railways were under no pecuniary obligation to the industrial companies in the division of receipts when the latter did this sort of switching on their own interior tracks. Large steel mills, etc., have their own tracks and deliver and receive cars from the railways at a convenient point agreed upon.

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* Lehman, Higginson & Co., vs. Texas Pacific Ry. Co. *et al.*

" Tap lines " built and owned by lumber companies, instead of being a small switching yard, as in the case of manufacturing concerns, are long lines extending from the railway into the region where the lumber is produced.

Elevator and Warehouse Service. In the conduct of railroad transportation a limited amount of storage has to be provided for, especially in the handling of grain. For this purpose, elevators are erected at primary markets to permit unloading and the release of cars. The railroads at first operated the elevators through agents, the expense of elevator service being incidental to the movement of the grain, but later railways definitely leased the elevators and paid the lessee the cost of elevation. The storage of cotton in warehouses in the South corresponds to elevator service for grain. A charge is usually made for all storage if the freight is not removed within a specified time.

Special Equipment Cars. Owing to the peculiar needs of large industrial concerns, special forms of cars have been developed, owned chiefly by such concerns. Refrigerator cars, especially adapted to the transportation of fruits, meats and other perishable foodstuffs, oil tank cars for carrying fuel and other oils, large furniture cars, automobile cars are examples of such special equipment. Formerly, the railroads paid so much per mile for the use of these special cars, at one time 0.6 cent, but later a per diem charge was substituted for most cases. Refrigerator cars are still handled chiefly on the mileage basis, the charge being about three-fourths cent per car-mile.

Demurrage. In the early days of railroading, it was customary for shippers to hold cars while loading and unloading almost indefinitely. Large manufacturing establishments even went so far as to hold cars loaded with fuel until the fuel was all consumed in their furnaces. Commission merchants still follow the practice in many cases of using the cars for storage while waiting for the expected rise in price of the cargo. About 1880, it became customary to charge demurrage for such retention of cars, amounting to a specified sum per day held. In many cases shippers still find it convenient to hold their cars and pay the necessary demurrage charge. Demurrage is sometimes averaged by allowing credit for cars released ahead of time. In the United States, the free time is usually two days and the charge is one dollar per day per car thereafter.

Car Load and Less than Car Load Rates. The distinction between car load and less than car load freight grew up at an early day of railroading. A generation ago, car load freight was rated per car load, the cars being about of uniform size. Competition caused railroads effectively to lower their rates by increasing the size of their cars, while retaining the car rate unchanged, thus offering more car capacity for the same money. Later, it became universal custom to charge on the basis of 100 lbs. or of the ton whether the freight was handled in car load or less than car load lots, but to use a different rate for the two conditions. Sometimes the distinction is made by placing less than car load lots in a different class and hence under a different rating. This difference in rate between car load and less than car load shipments, commonly called "the spread" in commercial circles, has given rise to intense feeling between wholesale and retail merchants. It is, however, a general custom to make a distinction in rates in one form or another between car load and less than car load shipments.

Special Commodity Rates. For many of the great staple commodities of commerce, special commodity rates are usually arranged. The chief of these commodities are:

1. Grain and grain products.
2. Live stock and dressed meats.
3. Cotton.
4. Lumber.
5. Bullion.

6. Fruits and vegetables.
7. Coal.
8. Brick, cement, lime.
9. Salt.
10. Ice.

On the great staple commodities of which the above are typical it is necessary to adjust rates in order to maintain equilibrium of traffic between the places of production and the various markets. Differentials in these cases have given rise to intense rivalries between cities, for example, Chicago, Milwaukee and Duluth, in competing for the market for Western grain. Commodity rates are without the regular classifications, and, when established, remove the application of the class rates to or from the points specified on the commodities affected, except when otherwise provided.

Classification of Operating Revenues. The Interstate Commerce Commission gives the following classification of operating revenues for steam roads:

I. Transportation—Rail line:
  101. Freight.
  102. Passenger.
  103. Excess baggage.
  104. Sleeping car.
  105. Parlor and chair car.
  106. Mail.
  107. Express.
  108. Other passenger train.
  109. Milk.
  110. Switching.
  111. Special service train.
  112. Other freight train.
  113. Water transfers—freight.
  114. Water transfers—passenger.
  115. Water transfers—vehicles and live stock.
  116. Water transfers—other.

II. Transportation—Water line:
  121. Freight.
  122. Passenger.

- 123. Excess baggage.
- 124. Other passenger service.
- 125. Mail.
- 126. Express.
- 127. Special service.
- 128. Other.

III. Incidental:

- 131. Dining and buffet.
- 132. Hotel and restaurant.
- 133. Station, train and boat privileges.
- 134. Parcel room.
- 135. Storage—freight.
- 136. Storage—baggage.
- 137. Demurrage.
- 138. Telegraph and telephone.
- 139. Grain elevator.
- 140. Stock yard.
- 141. Power.
- 142. Rents of buildings and other property.
- 143. Miscellaneous.

IV. Joint Facilities:

- 151. Joint facility—Cr.
- 152. Joint facility—Dr.

Of the two main groups of revenues, the first, or that from transportation, is by far the most important, and is the only source of revenue affected by the location. The percentage of revenue derived from these various sources is shown on page 132 for the year 1914.

Classification of Revenues for Electric Railways. The interstate Commerce Commission's classification of operating revenues on electric railways is as follows:

I. Revenue from Transportation:

- 1. Passenger.
- 2. Baggage.
- 3. Parlor, chair and special car.
- 4. Mail.
- 5. Express.
- 6. Milk.
- 7. Freight.

Item.	Per Cent of Total Revenues.	
	Class I Roads.	Class II Roads.
1. Freight	69.36	71.07
2. Passenger	23.02	21.59
3. Excess baggage	.25	.18
4. Parlor and chair car	.02	.02
5. Mail	1.82	1.42
6. Express	2.50	2.46
7. Milk (on pass. trains)	.32	.36
8. Other passenger train revenue	.21	.04
9. Switching	1.07	1.90
10. Special service train	.06	.13
11. Miscellaneous transportation	.23	.11
Total transportation	98.86	98.28
12. Station and train privileges	.10	.16
13. Parcel room receipts	.03	.01
14. Storage, freight	.07	.07
15. Storage, baggage	.02	.01
16. Car service	.35	.55
17. Telegraph and telephone	.05	.10
18. Rents of buildings, etc	.15	.34
19. Miscellaneous	.29	.48
Total non-transportation	1.06	1.72
20. Joint facilities, Dr	*.04*	*.04*
21. Joint facilities, Cr	.12	.04
Total	100.00	100 00

8. Switching.
9. Miscellaneous.

II. Revenues from Operations Other than **Transportation:**

10. Station and car privileges.
11. Parcel-room receipts.
12. Storage.
13. Car service.
14. Telegraph and telephone service.
15. Rents of tracks and terminals
16. Rents of equipment.
17. Rents of buildings and other property.
18. Power
19. Miscellaneous.

PART B

OPERATING CONDITIONS AFFECTING LOCATION

CHAPTER VIII

PERFORMANCE OF STEAM LOCOMOTIVES

Introduction. In order to decide many questions of grade and aligment intelligently, the engineer should be familiar with some of the characteristics of the motive power to be used. As a matter of fact, the two governing elements entering into economic location are the motive power and the resistance to be overcome. The limitations as to efficiency, tractive power, speed and ability to keep the track should be well understood by the locating engineer as well as by the operating officials.

A locomotive is a power plant, say of 1200 horsepower capacity, equivalent perhaps to the power plant required to furnish electric lights and street car service to a city of 25,000 population. This power plant must be designed to move across country at a speed of 35 to 60 miles per hour, to operate under the most unfavorable conditions of low temperatures, winds, storms, rain, and snow. When one contrasts such operating conditions with those of a stationary plant, well housed in a building that protects it from the inclemencies of the weather, insulated at every point to prevent losses due to radiation, one could scarcely expect to secure maximum efficiency of operation in the locomotive. It is not at all surprising, therefore, to find that power produced by a steam locomotive under its adverse operating conditions costs four or five times as much in some instances per horsepower as does power produced at a stationary plant.

Essential Features of a Locomotive. A steam locomotive consists essentially of (1) an internally fired boiler, which may have various accessories, for generating steam, (2) one or more pairs of cylinders, which may be simple or compound, for converting the heat energy of the steam into mechanical energy, and (3) the driving wheels for applying this mechanical energy by means of friction to the rails for the purpose of drawing the train load. Any one of these elements may be the limiting factor of locomotive performance under various conditions. At times, for example, at high speed, the boiler may not have sufficient generating capacity to furnish the cylinders with steam as rapidly as it is needed; on the other hand, at low speeds, the cylinders may be lacking in capacity at the boiler pressure available to exert the necessary force on the drivers; lastly, especially in wet weather, or on otherwise bad track, the adhesion of the wheels to the rails may be the limiting condition, and the size of the driving wheels always has a very important influence on the speed of the train. These three essentials of a locomotive are the three characteristics that are most intimately related to the work of the locating engineer and will be the subject of the brief study of the present chapter.

The Boiler. The boiler consists essentially of the furnace for the combustion of the fuel, the tubes and other heating surface for applying the heat generated in the furnace to the evaporation of water, and the front end arrangement for voiding the smoke.

The Grate. In the development of the steam locomotive, one of the difficulties has been to provide sufficient grate area for the combustion of the coal necessary to furnish the heat required. On the older types of boilers on which the fire-box was included between the driving wheels and hence limited in width, there was a decided lack of grate area. This defect has been remedied to a considerable extent by extending the boiler so that the fire-box is behind the drivers and consequently its width is not limited by the lateral distance between the drivers. Some of the railroads that burn anthracite coal on their locomotives use the Wooten type of boiler, on which the grate is widened by spreading the fire-box at the bottom, which arrangement necessitates placing the engine driver's cab at the middle of the boiler. The length of the grate is limited in hand-fired boilers to the greatest distance that a fireman can throw the coal with his scoop as he shovels it in at the furnace door. The introduction of automatic stokers eliminates this difficulty in coal burners and it does not exist in oil burners, for the oil is fed into the furnace in the form of a spray from an atomizing nozzle.

The heating capacity of any grate depends to such an extent upon the skill of the fireman and the quality of coal burned that general figures cannot be well given as to the results obtained per pound of coal per square foot of grate area. If, for example, the fire is crowded too much by putting on an excess of coal, dense volumes of smoke arise from the stack, which indicate that unburned carbon is being emitted into the air in the form of soot, and hence is being wasted. On the other hand, if the fire is allowed to become too thin over the grate, or is not evenly spread over the grate, an excess of air, that is, more than required for combustion, passes through the grate and out of the stack, causing a loss, for the air carries away heat units with it. About 65 sq.ft. marked the limit of grate area for hand-fired boilers, but the mechanical stoker permits over 100 sq.ft. to be used. The maximum rate of combustion on a consolidation locomotive tested at the University of Illinois was 224.5 lbs. of coal per square foot of grate area per hour.* At such a rate, there is a decided loss in efficiency, amounting to perhaps 30 per cent.

The quality of fuel has so determining an influence on the steam-producing capacity of a locomotive that a brief discussion of this factor seems necessary in this connection.

Fuel. The fuels used in locomotive operation are practically limited at the present time to coal and petroleum, the use of wood having been discontinued because of its low heat value and its growing scarcity.

Peat is similar to a very low grade of coal, being formed by the partial decay of mosses and other bog plants under water. At the present time, there is an effort being made to use peat in locomotives owing to the high price of the better grades of coal. It has a heating value of 3000 to 4000 B.t.u. per pound.

Lignite is a low grade of coal, most of the lignites having been formed after the Carboniferous Age. Lignites abound in the Rocky Mountain states and is used much as fuel, although the fire-box must be specially designed for its use. It contains much volatile matter and after combustion leaves a fine white ash with practically no clinker. The heating value is about 4000 to

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* Bulletin No. 82, Engineering Exp. Sta., University of Illinois.

6000 B.t.u. per pound, although some of the lignites run about 50 per cent higher than these figures.

Bituminous coal, or coal containing bitumen, comprises many varieties and is found in nearly all parts of the United States. Its heating value varies from 6000 to 12,000 B.t.u. per pound.

Anthracite coal was formed geologically by the action of heat and pressure upon other forms of coal, thereby driving off most of the volatile constituents, leaving chiefly carbon and mineral matter. It burns with but very little visible smoke and leaves a fine ash and small amount of clinker. It is used mainly on the roads operating through the eastern part of Pennsylvania. Its calorific value is but little above that of the better grades of bituminous coal, amounting to about 13,000 B.t.u. per pound.

Fuel Oil is used on the Southern Pacific and other railways operating through oil-producing fields. It is conveniently fired and has a high calorific value, viz., about 21,000 B.t.u. per pound. The U. S. Bureau of Mines gives the following requirements for fuel oil:

Heating value shall be over 18,000 B.t.u. per pound.
Flash point shall be below 60° C. (140° F.)
Specific gravity shall be between 0.85 and 0.95.
Water shall be less than 2 per cent.
Sulphur shall be less than 1 per cent.

The average heating values of petroleum oil are as follows:

	B t.u. per lb.
California asphaltic, crude	18,570
Mid-continent, crude	19,720
Mexican, crude	18,000
Gasoline	21,120
Kerosene	20,130

The price of fuel has more than doubled within the past fifteen years, consequently the kind of fuel available will have much to do with the success of a railroad.

Table XIV shows average heating values and other properties of different coals of the United States.

Heating Area. In order to effect the maximum evaporation of water in the boiler, it is important to secure as large an area

TABLE XIV

ANALYSIS OF TYPICAL COALS

Source of Coal.	Analysis, Per Cent.				Heat Value, B.t.u.
	Moisture.	Volatile.	Fixed Carbon	Ash.	
Alabama	3	29	57	11	13,100
Arkansas	6	10	70	14	12,500
California	18	35	31	16	8,500
Colorado	9	34	45	12	11,300
Georgia	4	16	66	14	12,800
Illinois	12	37	42	9	11,400
Indiana	11	35	47	7	11,400
Iowa	14	33	37	16	10,000
Kansas	5	33	49	13	12,200
Kentucky	8	38	45	9	12,200
Maryland	3	18	72	7	14,000
Missouri	13	34	40	13	10,600
Montana	8	32	44	16	10,000
New Mexico	3	35	48	14	12,000
N. Dakota	36	32	24	8	7,000
Ohio	7	34	49	10	12,200
Oklahoma	7	35	48	10	12,200
Pennsylvania, Bit.	3	35	56	6	13,500
Pennsylvania, Ant.	3	18	69	10	13,800
Tennessee	5	33	51	11	12,500
Texas	34	29	30	7	7,400
Utah	6	39	46	9	12,200
Virginia, Pocah.	2	17	75	6	14,600
Washington	6	31	50	13	12,000
W. Virginia	3	23	69	5	14,000
Wyoming	9	31	34	21	10,000

of heating surface as possible. To this end, tubes are placed in the boiler in front of the fire-box so that the heated gases may pass through them and thus increase the area of contact with water-covered surface, for the amount of heat transmitted varies directly as the area exposed. The heating area of a Mikado type of locomotive used on the Chesapeake and Ohio Railway was as follows:

Fire-box	283 sq.ft.
Tubes	3740 sq.ft.
Water tubes	28
Total	4051

It will be readily observed that the tubes form by far the largest portion of the heating surface, and, as a matter of fact, they afford about the only means of increasing locomotive capacity with respect to heating area. In the first locomotive built there was but one large tube through which the flames passed, but the increased steaming capacity of multiple tubes was soon understood, and since that time, the tubes have been increased in number and diminished in diameter. In recent types of locomotives, the use of the brick arch, which deflects the heated gases more effectively against the heating area, has accomplished marked economy in fuel consumption, amounting to 12 per cent in some instances.

Water Supply. The quality of water available for use in locomotives has much to do with their steaming capacity. Calcium and magnesium carbonates and other salts cause deposits or " boiler scale " to form which may very greatly decrease the steaming capacity as well as to injure the boiler itself. Impurities in water, whether they occur in suspension or in solution are detrimental in that they (1) deposit scale in the boiler, (2) corrode the boiler and its fittings, (3) cause injury to boiler plates by overheating, and (4) cause the water to foam.

In dealing with hard water it is necessary to recognize two kinds of hardness, sometimes designated as temporary and permanent hardness. The first is caused by carbonates of calcium and magnesium, which are normally insoluble in water but which are held in solution as bicarbonates by virtue of the carbon dioxide present in the water. When quicklime is added to such water, the carbon dioxide is removed by union with the lime, forming more carbonate, whereupon the carbonates that were already in the water as well as those formed in the process are precipitated. The second form, or permanent hardness, is caused by the sulphates of calcium and magnesium and cannot be so readily removed. However, by the introduction of " soda ash," or anhydrous sodium carbonate, calcium and magnesium carbonates are precipitated, leaving sodium sulphate. The scale formed by the latter can be easily blown out, but its presence may cause the boiler to foam. These processes are brought about in practice by a water softener consisting of a standpipe in which the water is allowed to stand after application of the softening chemicals and a filter through which it passes on its way to the tank. The employment of other chemicals has been suggested, but because of their cheapness, lime and soda ash are almost universally used for this purpose.

A chemical analysis of the water to be treated shows how much of the reagent is required to precipitate the objectionable substances and the entire process is capable of very accurate control. The benefits derived from the use of water softening are:

1. Fewer boiler failures due to leaking.
2. Longer life of flues and fire-box sheets.
3. Reduced cost of labor for repairing and cleaning boilers.
4. Increased locomotive mileage between shoppings.
5. Increased ton-mileage per pound of coal, owing to lessening incrustation.
6. Decreased number of locomotives in service.
7. Shorter time required for locomotives to make their runs.
8. Improved morale, due to better operating conditions.
9. Fewer interruptions of traffic due to engine failures.

The Chicago and Northwestern, Chicago, Rock Island and Pacific, Atchison, Topeka and Santa Fé, Union Pacific, Southern Pacific, Pittsburg and Lake Erie, as well as others, have installed water softeners and uniformly report economies effected thereby. The Santa Fé reported a 74 per cent decrease in boiler failures; the Northwestern realized the following economies which are typical:

Decrease in boiler failures..........	79 per cent
Decrease in fuel per 1000 ton-miles .	42 per cent
Decrease in number of engine-miles .	3.1 per cent

Scale about $\frac{1}{8}$ in. thick has been found to cause a loss of heat of 10 to 12 per cent. The economies effected are further exemplified by the conditions on another Western railroad,* where the softeners have been in use on two divisions since 1905 and represent a total investment of $136,000. The average amount of water treated is 463,000,000 gals. per day for locomotive and stationary boilers, with about 3.3 lbs. of incrusting solids per 1000 gals. The annual saving was estimated at $166,000, or 9.8 cents per 1000 gals. treated, while the cost of treatment was only 3.7 cents.

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* Proc. Am. Ry. Eng. Assn., Vol. XV, p. 693.

The necessity of securing the greatest possible economy in the operation of locomotives, by obtaining the maximum train load and by saving in fuel, which is one of the largest operating expenses and which is increasing in price every year, is becoming more and more acute, hence, it is imperative that good water be obtained. This applies to particularly difficult operating conditions, such as high speeds and long, steep grades.

Boiler Losses. The chief heat losses of a boiler of a locomotive are *spark losses* and *radiation losses.* Because of the heavy draft through the grate and over the heating surface of a locomotive resulting from the exhaust of the cylinders passing through the stack, much coal that is only partially burned escapes to the smoke box at the front end or out of the stack entirely as sparks. These sparks may amount to a considerable loss in fuel and heat, their heat value varying from 4 to 15 per cent of the total. When it is remembered that the fuel expense of road engines varies from 10 to 14 per cent of the total operating expenses, it is seen that this loss is serious. The heavy draft due to hard pulling on heavy grades is particularly wasteful in this respect.

That the loss due to radiation must be considerable is evident from the rapidity with which the pressure in the boiler of a standing locomotive falls off. The pressure has been observed to decrease from 150 lbs. to zero in ten to fifteen hours, the exact time depending upon the temperature of the surrounding air, the velocity of the wind and other conditions. The rate of radiation is necessarily much greater when the locomotive is in motion than when standing. Locomotive boilers are insulated so far as possible in order to reduce radiation to a minimum. Professor W. F. M. Goss conducted an elaborate and very interesting series of experiments in co-operation with the Chicago and Northwestern Railway to determine the radiation losses when the locomotive is in motion.* That the speed of the train has much to do with the radiation losses was evident from Professor Goss' experiments, the losses varying directly with the speed. The radiation was found to be about twice as rapid as 30 M.P.H. as at rest. At this speed, the radiation losses amount to from 1 to 5 per cent of the capacity of the locomotive, the former limit occurring in summer and the latter in winter.

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* "Locomotive Performance," W. F. M. Goss, p. 186.

The Cylinders. It is in the cylinders where the heat energy of the steam is converted into mechanical energy that can be transmitted to the drivers. As the steam enters the cylinders, it exerts full boiler pressure on the piston until the latter moves forward to the point of cut-off where the valve closes the connection with the boiler. From this point, the steam acts expansively against the piston head. Fig. 8 shows typical indicator cards of a consolidation locomotive* at various speeds. The position of the cut-off is controlled by the engine driver by means of the large reverse lever in the cab. At low speed, when it is desired to exert the maximum tractive effort, the cut-off is shifted ahead in order to allow the steam to act at full pressure over a greater portion of the stroke, but at higher speeds the cut-off is shifted to perhaps $\frac{1}{8}$ stroke in order to use the steam expansively and thus more economically. Inasmuch as locomotives are not designed to operate at constant speeds as are stationary engines, which are controlled by a governor, the speed is a very important factor in its effect upon the thermodynamic efficiency as well as upon the mechanical efficiency of the locomotive, a fact that the locating engineer should ever keep in mind. There is a " critical speed " at which a locomotive operates at a maximum efficiency, but this speed varies with the steam pressure and other conditions. On a locomotive tested by Professor Goss, the critical speed was 200 R.P.M.

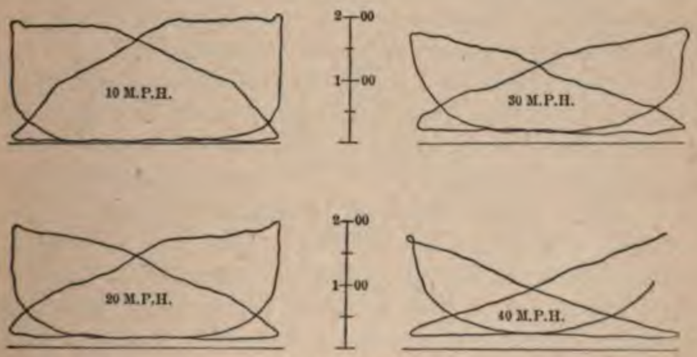

Fig. 8.—Typical Locomotive Indicator Cards at Various Speeds.

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* Bulletin No. 82, Engineering Exp. Sta., University of Illinois.

The necessity of securing the greatest possible economy in the operation of locomotives, by obtaining the maximum train load and by saving in fuel, which is one of the largest operating expenses and which is increasing in price every year, is becoming more and more acute, hence, it is imperative that good water be obtained. This applies to particularly difficult operating conditions, such as high speeds and long, steep grades.

Boiler Losses. The chief heat losses of a boiler of a locomotive are *spark losses* and *radiation losses.* Because of the heavy draft through the grate and over the heating surface of a locomotive resulting from the exhaust of the cylinders passing through the stack, much coal that is only partially burned escapes to the smoke box at the front end or out of the stack entirely as sparks. These sparks may amount to a considerable loss in fuel and heat, their heat value varying from 4 to 15 per cent of the total. When it is remembered that the fuel expense of road engines varies from 10 to 14 per cent of the total operating expenses, it is seen that this loss is serious. The heavy draft due to hard pulling on heavy grades is particularly wasteful in this respect.

That the loss due to radiation must be considerable is evident from the rapidity with which the pressure in the boiler of a standing locomotive falls off. The pressure has been observed to decrease from 150 lbs. to zero in ten to fifteen hours, the exact time depending upon the temperature of the surrounding air, the velocity of the wind and other conditions. The rate of radiation is necessarily much greater when the locomotive is in motion than when standing. Locomotive boilers are insulated so far as possible in order to reduce radiation to a minimum. Professor W. F. M. Goss conducted an elaborate and very interesting series of experiments in co-operation with the Chicago and Northwestern Railway to determine the radiation losses when the locomotive is in motion.* That the speed of the train has much to do with the radiation losses was evident from Professor Goss' experiments, the losses varying directly with the speed. The radiation was found to be about twice as rapid as 30 M.P.H. as at rest. At this speed, the radiation losses amount to from 1 to 5 per cent of the capacity of the locomotive, the former limit occurring in summer and the latter in winter.

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* "Locomotive Performance," W. F. M. Goss, p. 186.

The Cylinders. It is in the cylinders where the heat energy of the steam is converted into mechanical energy that can be transmitted to the drivers. As the steam enters the cylinders, it exerts full boiler pressure on the piston until the latter moves forward to the point of cut-off where the valve closes the connection with the boiler. From this point, the steam acts expansively against the piston head. Fig. 8 shows typical indicator cards of a consolidation locomotive* at various speeds. The position of the cut-off is controlled by the engine driver by means of the large reverse lever in the cab. At low speed, when it is desired to exert the maximum tractive effort, the cut-off is shifted ahead in order to allow the steam to act at full pressure over a greater portion of the stroke, but at higher speeds the cut-off is shifted to perhaps $\frac{1}{8}$ stroke in order to use the steam expansively and thus more economically. Inasmuch as locomotives are not designed to operate at constant speeds as are stationary engines, which are controlled by a governor, the speed is a very important factor in its effect upon the thermodynamic efficiency as well as upon the mechanical efficiency of the locomotive, a fact that the locating engineer should ever keep in mind. There is a " critical speed " at which a locomotive operates at a maximum efficiency, but this speed varies with the steam pressure and other conditions. On a locomotive tested by Professor Goss, the critical speed was 200 R.P.M.

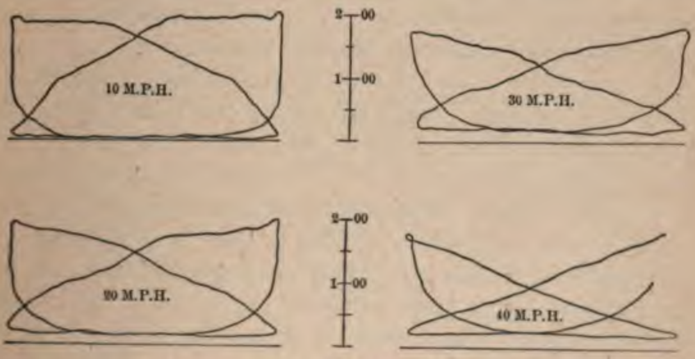

Fig. 8.—Typical Locomotive Indicator Cards at Various Speeds.

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* Bulletin No. 82, Engineering Exp. Sta., University of Illinois.

increased ability to haul full tonnage at greater speeds by the use of superheated steam.

Compound Locomotives. By allowing the steam to expand through two cylinders in succession, the first or high-pressure cylinder exhausting into the second or low-pressure cylinder, and the latter into open air, considerable economy in fuel and water consumption is effected. The low final pressure results in a mild even exhaust which improves the action of the draft, especially when the engine is working at low speed under a long cut-off. Compound locomotives are of three principal types, viz., the tandem compound, the balanced compound, and the Mallet compound. In the first, the high-pressure cylinder is placed in front of the low-pressure cylinder, the two piston heads being on the same rod. With this arrangement, the guides, crosshead and connecting rods are similar to those for a single-expansion locomotive.

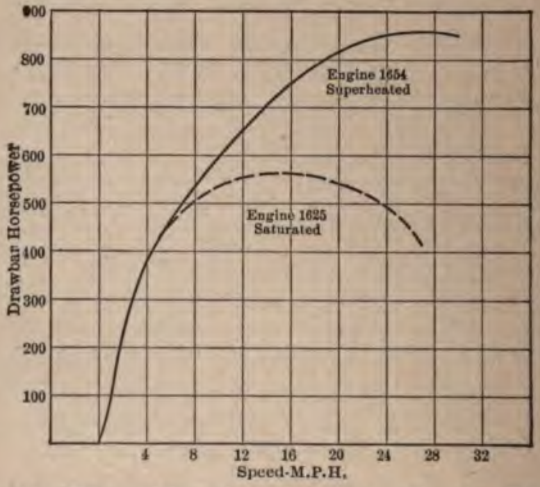

FIG. 10.—Effect of Superheated Steam on Tractive Effect.

The characteristic of the balanced compound is that the reciprocating parts are so arranged as to be self-balancing. In all two-cylinder types of locomotive, either single expansion or compound, it is necessary to counterbalance the reciprocating parts by means of weights added to the driving wheels. Only the horizontal component of the inertia effect of these counterweights is needed to counteract the effect of the reciprocating parts, consequently the vertical component of such counterweights must be overcome by the reaction of the track. This arrangement is frequently unsatisfactory, especially for heavy locomotives operating at high speeds, because it causes severe strains in the track and in bridges over which the track passes. This condition of affairs led to the introduction of the balanced compound locomotive, in which the reciprocating parts are balanced against each other, permitting the rotating counterweights on the wheels to be largely removed, thus avoiding the vertical shocks and reducing the strains in the track and bridges to those caused by the weight of the locomotive only. Consequently, with a self-balanced arrangement of reciprocating parts, the weight on the drivers can be increased without adding to the stresses in the track and higher speeds can be attained without inducing so severe strain in the locomotive. The two cylinders are usually placed side by side, the low-pressure being inside the locomotive frame and the high-pressure cylinder outside, separate guides being required of course, since their actions are not together, but at 90 degrees with each other. The inner connecting rods are attached to cranks in the axles while the outer connecting rods are connected to wrist pins on the drivers.

The Mallet articulated compound locomotive was devised in response to a demand for a locomotive having a very large tractive power and at the same time a flexible wheel base. The width of the locomotive being limited by track conditions, the only recourse was to extend the locomotive along the track. The driving wheels are divided into two groups, the rear group being attached rigidly to the locomotive frame while the front group operates on a swivel so that the whole passes around curves as readily as the heavy locomotives of the ordinary type. The rear group of wheels are driven by the high-pressure cylinders and the forward group are driven by the low-pressure cylinders. In starting, or in cases of supreme effort being demanded, live steam can be admitted directly into all four cylinders. Locomotives of the Mallet type may have two, three, or four pairs of wheels in each group. They are especially suitable for heavy freight hauling on steep grades and for pusher service. Recently a locomotive has been built with a third pair of cylinders which operate the wheels under the tender as drivers.

Driving Mechanism. *Diameter of Wheels.* The diameter of the driving wheels for any given speed determines the number of revolutions per minute of the drivers, and hence determines the rate of piston travel. A rule that has been much followed in America was to make the diameter of the wheels in inches equal to the desired speed in miles per hour, which required 336 R.P.M. for normal operation. The disadvantage of such rapid piston travel is being appreciated and at present there is a tendency to increase the diameter of the driving wheels. Foreign locomotive builders have long used larger driving wheels than have been the practice in America. When it is realized that at every stroke of the piston a certain amount of steam escapes, it is obvious that the high speeds sometimes necessitated in operation constitutes a severe trial on boiler capacity.

Internal Friction. The internal friction of a locomotive depends upon the design of the mechanism, the lubrication, the temperature and the speed of operation. Internal friction is greater when a locomotive is first starting than after it has been running for some time, which fact makes it harder for an engine to start a train on a grade than to keep it going after it is started.

Length of Wheel Base. The length of the wheel base will have much to do with the ability of the locomotive to pass around curves. It is necessary that all drivers operated from one pair of cylinders should be held in a straight line, or nearly so at least, on a rigid wheel base because of the action of the reciprocating parts. It is also desirable to have as much of the weight of the locomotive as possible concentrated on the drivers in order to increase the adhesion available for tractive effort. To facilitate the passage of curves, locomotives having long wheel bases are frequently made with some of the drivers " blind," that is, without flanges. It is doubtful if such a practice improves conditions greatly. Recently some locomotives have been made with a provision for a lateral movement of the front driver in order to accomplish the same object.

Classification of Locomotives. The larger manufacturers of locomotives have adopted systems of classifying their product, the classification usually being according to the number of wheels and the weight. In the Baldwin classification, the type of locomotive is represented by figures separated by dashes, the figures indicating the wheel groupings, e.g., a 2-8-2 locomotive is a

Mikado type having two truck wheels, eight drivers and two trailers, thus o OOOO o. The American Locomotive Company use a similar scheme but omit the hyphens and add a figure that represents the weight of the locomotive in thousand pounds, thus a 282-260 locomotive would be one of the Mikado type weighing 260 thousand pounds. Table XV shows the classification of the different types of locomotives that have been used in America.

TABLE XV

CLASSIFICATION OF LOCOMOTIVES

Full Truck or Bogie Class	∠oo Oo	**Single Driver**	**4-2-2**	
	∠ooOO	**American**	**4-4-0**	— 1
	∠ooOOo	**Atlantic**	**4-4-2**	— 3
	∠ooOOO	**Ten Wheel**	**4-6-0**	— 6
	∠ooOOOo	**Pacific**	**4-6-2**	— 7
	∠ooOOOO	**Twelve Wheel**	**4-8-0**	
	∠ooOOOOO	**Mastodon**	**4-10-0**	— 10
Pony or Two Wheel Truck Class	∠o OO o	**Columbia**	**2-4-2**	—
	∠o OOO	**Mogul**	**2-6-0**	— 4
	∠o OOOo	**Prairie**	**2-6-2**	— 5
	∠o OOOO	**Consolidation**	**2-8-0**	— 8
	∠o OOOOo	**Mikado**	**2-8-2**	— 9
	∠o OOOOO	**Decapod**	**2-10-0**	— 11
	∠o OOOOOo	**Santa Fe**	**2-10-2**	— 12
	∠o OOOOOO	**Centipede**	**2-12-0**	
Switcher Class	∠OO	**Four Wheel**	**0-4-0**	
	∠oOO	**Four Coupled**	**2-4-0**	
	∠OOo	" "	**0-4-2**	
	∠OOO	**Six** "	**0-6-0**	
	∠OOOO	**Eight** "	**0-8-0**	
	∠OOOOO	**Ten** "	**0-10-0**	
	∠OOO OOO	**Articulated**	**0-6-6-0**	
Forney Class	∠OOoo	**Forney**	**0-4-4**	
	∠OOOoo	"	**0-6-4**	
	∠ooOo	"	**4-2-2**	
	∠o OOoo	"	**2-4-4**	
	∠o OOooo	"	**2-4-6**	
Mallet or Articulated	∠o OO OO		**2-4-4-0**	
	∠o OOO OOO		**2-6-6-0**	
	∠o OOOO OOOO		**2-8-8-0**	
	∠o OOOO OOOOo		**2-8-8-2**	

Power of a Locomotive. For the solution of many of the problems involved in railway location, the performance of the locomotive must be known either from tests or from calculation with definiteness. The following method of calculating the drawbar pull at various speeds is taken from the Manual of the American Railway Engineering Association.

(1) The actual drawbar pull of the locomotive at various speeds should be used in making estimates with reference to economic values of various locations of line and grade, where such drawbar pull is known. Where not known, the drawbar pull should be calculated. In comparing a new line with an existing line the same percentage of efficiency of drawbar pull should be used in both cases.

(2) The tractive power of a locomotive depends upon its steam-producing capacity, the boiler pressure, the adhesion, and the size of the cylinders and drivers.

(3) The steam-producing capacity of a locomotive depends mainly upon the quantity and quality of fuel burned, and the area of the heating surface.

(4) Knowing the area of the heating surface, the average steam production of locomotives burning bituminous and similar coals can be estimated by the use of Table XVI, assuming the maximum quantity of coal that can be properly fired and consumed per hour to be as follows:

Hand-fired locomotives	4000 lbs. per hour
Stoker-fired locomotives with grates less than 70 sq.ft.	6000 lbs. per hour
Stoker-fired locomotives with grates of 70 sq.ft. or over	8000 lbs. per hour

These amounts are to be understood as the average hourly fuel consumption that may reasonably be expected to be maintained throughout the periods when the locomotive is working steam.

(5) The maximum velocity at which full cut-off can be maintained can be found by dividing the pounds steam produced per minute by the quantity of steam used per revolution of the drivers, as shown in Table XVII. This number of revolutions can be converted to miles per hour, which gives the maximum speed at which full cut-off can be maintained, which speed is called M. This conversion can be conveniently made by the formula,

$$\text{M.P.H.} = \frac{\text{r.p.m.} \times \text{diameter of drivers}}{336.13}$$

(6) Tractive power of a locomotive is greatest at starting, gradually reducing to the maximum velocity (M) at which full cut-off can be main-

tained. At speeds above this velocity the tractive power decreases more rapidly. The tractive power at any multiple of M is practically a fixed percentage of the tractive power at M. These fixed percentages are different for compound types than for simple locomotives.

(7) Knowing the steam production of a locomotive and the maximum velocity at which full cut-off can be maintained (M), the indicated horsepower of the locomotive can be obtained for velocity M or higher velocities by dividing the total steam produced per hour by the quantity of steam used per I.H.P. hour, as given in Table XVIII, after applying the corrections for proper boiler pressure in the case of a locomotive using saturated steam.

TABLE XVI

AVERAGE EVAPORATION IN LOCOMOTIVE BOILERS

BASED ON FEED WATER AT 60° F.; BOILER PRESSURE 200 LBS.

Lbs. Coal per Sq.ft. Heating Surface per Hour.	POUNDS OF STEAM PER POUND OF COAL OF GIVEN THERMAL VALUE.					
	15,000 B.t.u.	14,000 B.t.u.	13,000 B.t.u.	12,000 B.t.u.	11,000 B.t.u.	10,000 B.t.u.
0.8	7.86	7.34	6.81	6.29	5.76	5.24
0.9	7.58	7.07	6.57	6.06	5.56	5.05
1.0	7.31	6.82	6.34	5.85	5.36	4.87
1.1	7.06	6.59	6.12	5.65	5.18	4.71
1.2	6.82	6.37	5.91	5.46	5.00	4.55
1.3	6.59	6.15	5.71	5.27	4.83	4.39
1.4	6.37	5.95	5.82	5.10	4.67	4.25
1.5	6.17	5.76	5.35	4.94	4.52	4.11
1.6	5.97	5.57	5.18	4.78	4.38	3.98
1.7	5.79	5.40	5.02	4.63	4.25	3.86
1.8	5.61	5.24	4.86	4.49	4.12	3.74
1.9	5.44	5.08	4.71	4.35	3.99	3.63
2.0	5.27	4.92	4.57	4.22	3.86	3.51
2.1	5.12	4.78	4.44	4.10	3.75	3.41
2.2	4.97	4.64	4.31	3.98	3.64	3.31
2.3	4.83	4.51	4.19	3.86	3.54	3.22
2.4	4.69	4.38	4.07	3.75	3.44	3.13
2.5	4.56	4.26	3.95	3.65	3.34	3.04
2.6	4.44	4.14	3.84	3.55	3.25	2.96
2.7	4.32	4.03	3.74	3.46	3.17	2.88
2.8	4.21	3.93	3.64	3.37	3.09	2.80
2.9	4.10	3.83	3.55	3.28	3.01	2.73
3.0	3.99	3.73	3.46	3.19	2.93	2.66

On bad water districts, deduct the following from above quantities:
For each $\frac{1}{16}$ in. of boiler scale, 10 per cent.
For each grain per U. S. gallon of foaming salts in average feed water, 1 per cent.

TABLE XVII

WEIGHT OF STEAM USED IN ONE FOOT OF STROKE IN LOCOMOTIVE CYLINDERS, POUNDS

(*a*) FOR LOCOMOTIVES USING SATURATED STEAM. CYLINDER DIAMETER IS FOR HIGH-PRESSURE CYLINDERS IN COMPOUND LOCOMOTIVES

Diameter of Cylinder, Inches.	GAUGE PRESSURE, POUNDS.						
	160	170	180	190	200	210	220
12	0.304	0.321	0.337	0.354	0.370	0.389	0.405
13	0.357	0.376	0.396	0.415	0.435	0.456	0.475
14	0.414	0.436	0.459	0.482	0.504	0.529	0.551
15	0.476	0.501	0.527	0.553	0.579	0.607	0.663
15½	0.508	0.535	0.562	0.590	0.618	0.649	0.675
16	0.541	0.570	0.599	0.629	0.658	0.691	0.720
17	0.611	0.643	0.676	0.710	0.744	0.780	0.812
18	0.685	0.722	0.759	0.796	0.834	0.875	0.911
18½	0.724	0.762	0.801	0.841	0.881	0.924	0.962
19	0.763	0.804	0.845	0.887	0.928	0.975	1.015
19½	0.804	0.847	0.890	0.934	0.978	1.027	1.069
20	0.846	0.891	0.936	0.983	1.029	1.080	1.125
20½	0.888	0.936	0.984	1.032	1.081	1.134	1.181
21	0.932	0.982	1.032	1.083	1.134	1.191	1.240
22	1.023	1.078	1.133	1.189	1.245	1.307	1.361
23	1.118	1.178	1.238	1.300	1.361	1.428	1.487
28	1.657	1.745	1.835	1.926	2.017	2.117	2.204

For weight of steam used per revolution of drivers at full cut-off: Multiply the tabular quantity by four times the length of stroke in feet for simple and four-cylinder compounds. For two-cylinder compounds, multiply by two times the length of stroke.

(*b*) FOR SIMPLE LOCOMOTIVES USING SUPERHEATED STEAM

Diameter of Cylinder, Inches.	GAUGE PRESSURE, POUNDS.					
	160	170	180	190	200	210
18	0.415	0.443	0.470	0.498	0.524	0.551
19	0.465	0.496	0.526	0.557	0.587	0.618
20	0.515	0.549	0.582	0.617	0.650	0.684
21	0.565	0.605	0.641	0.679	0.715	0.752
22	0.623	0.665	0.705	0.747	0.787	0.827
23	0.682	0.728	0.772	0.818	0.861	0.905
24	0.741	0.791	0.838	0.889	0.931	0.984
25	0.804	0.859	0.910	0.965	1.016	1.065
26	0.868	0.927	0.983	1.041	1.097	1.150
27	0.937	1.000	1.057	1.123	1.183	1.241
28	1.008	1.078	1.143	1.209	1.275	1.340
29	1.083	1.156	1.225	1.299	1.368	1.438
30	1.157	1.234	1.308	1.387	1.460	1.533

This assumes a superheat of 200° Fahrenheit, and a drop of 5 lbs. per sq.in. in pressure between the boilers and the cylinders.

TABLE XVIII

POUNDS OF STEAM PER I.H.P. FOR VARIOUS MULTIPLES OF *M*

(*a*) FOR LOCOMOTIVES USING SATURATED STEAM. *M* IS THE MAXIMUM VELOCITY IN MILES PER HOUR AT FULL CUT-OFF. BOILER PRESSURE 200 LBS.

Velocity / *M*	LBS. STEAM PER I.H.P. HR.		Velocity / *M*	LBS. STEAM PER I.H.P. HR.	
	Simple Locomotive.	Compound Locomotive.		Simple Locomotive.	Compound Locomotive.
1.0	38.30	25.80	2.9	24.37	21.04
1.1	36.46	24.36	3.0	24.22	21.21
1.2	34.89	23.24	3.2	24.00	21.57
1.3	33.56	22.35	3.4	23.85	21.93
1.4	32.41	21.65	3.6	23.80	22.27
1.5	31.40	21.14	3.8	23.80	22.57
1.6	30.49	20.77	4.0	23.87	22.85
1.7	29.67	20.52	4.25	24.05	23.22
1.8	28.93	20.40	4.50	24.24	23.56
1.9	28.25	20.40	4.75	24.44	23.85
2.0	27.62	20.40	5.00	24.64	24.15
2.1	27.05	20.40	5.5	24.98	24.70
2.2	26.52	20.40	6.0	25.20	
2.3	26.06	20.40	6.5	25.45	
2.4	25.67	20.40	7.0	25.60	
2.5	25.32	20.47	7.5	25.70	
2.6	25.02	20.60	8.0	25.80	
2.7	24.76	20.73	9.0	25.90	
2.8	24.54	20.88			

For other boiler pressures, take the following percentages of the values given in the table: 160 lbs., 103%; 170 lbs., 102.1%; 180 lbs., 101.3%; 190 lbs., 100.6%; 210 lbs., 99.5%; 220 lbs., 99.2%.

(*b*) FOR SIMPLE LOCOMOTIVES USING SUPERHEATED STEAM

Velocity / *M*	Lbs. Steam per I.H.P.	Velocity / *M*	Lbs. Steam per I.H.P.
1.0	24.00	2.8	18.70
1.1	23.58	2.9	18.55
1.2	23.10	3.0	18.40
1.3	22.74	3.2	18.20
1.4	22.28	3.4	18.00
1.5	21.92	3.6	17.79
1.6	21.55	3.8	17.60
1.7	21.10	4.0	17.44
1.8	20.90	4.25	17.26
1.9	20.59	4.5	17.10
2.0	20.32	4.75	16.96
2.1	20.05	5.0	16.86
2.2	19.81	5.5	16.72
2.3	19.60	6.0	16.63
2.4	19.40	6.5	16.62
2.5	19.22	7.0	16.62
2.6	19.02	8.0	16.62
2.7	18.86		

(8) Horsepower can be converted into tractive power by the formula, tractive power equals 375 times the horsepower, divided by the velocity in miles per hour.

(9) Where the I.H.P. at M velocity has been converted into cylinder tractive power, the cylinder tractive power at other multiples of M can be determined by using the percentages given in Table XIX without first calculating the I.H.P. for various multiples of M.

(10) Available drawbar pull on level tangent is the cylinder tractive power less the sum of resistance from the cylinder to the rim of the drivers, the resistance through the trucks of the engine and tender, and the "head end," or velocity resistance. These resistances are given by the formulas,

Resistance to rim of drivers $= 18.7t + 80n$;
Resistance of engine and tender tracks $= 2.6T + 20N$;
Head end or air resistance $= 0.002V^2A$, or for average locomotives, $0.25V^2$.

t being the weight in tons on the drivers, n the number of driving axles, T the total weight in tons of the engine and tender, N the total number of truck axles, V the velocity in miles per hour, A the area of the head end in square feet, averaging for most locomotives about 125 sq.ft.

At low speeds, the adhesion of drivers should be considered and available drawbar pull should never be estimated greater than 30 per cent of the weight on the drivers at starting with the use of sand, and 25 per cent of weight on drivers at running speeds.

As an illustration of this method of calculating drawbar pull, consider a simple hand-fired consolidation locomotive using saturated steam, total weight of engine and tender 329,000 lbs., weight on drivers, 176,200 lbs., 3200 sq. ft. heating surface, 200 lbs. boiler pressure, burning Indiana No. 3 coal with 11,011 B.t.u. per lb., cylinders 22 by 28 ins., drivers 56 ins. in diameter. To calculate the drawbar pull at 22 M.P.H. on level tangent:

$\frac{4000}{3200} = 1.25$ lb. per hour square foot heating surface. From Table XVI, this would give 4.92 lbs. steam per pound coal. $4.92 \times \frac{4000}{60} = 328$ lbs. steam per minute as boiler capacity. From Table XVII, 1.245 lb. steam is used per foot of stroke. $\frac{328}{(1.245 \times 2)}$ $= 132$ strokes per minute for M, equals 33 R.P.M. $M =$

TABLE XIX

PER CENT CYLINDER TRACTIVE POWER FOR VARIOUS MULTIPLIES OF *M*

(*a*) FOR LOCOMOTIVES USING SATURATED STEAM

Velocity, *M*.	Comp'd, Per cent.	Simple, Per cent.	Velocity, *M*.	Comp'd, Per cent.	Simple, Per cent.	Velocity, *M*.	Simple, Per cent.
Start	135.00	106.00	3.6	32.40	44.75	6.4	23.59
0.5	103.00	103.00	3.7	31.25	43.56	6.5	23.18
1.0	100.00	100.00	3.8	30.10	42.39	6.6	22.79
1.1	96.28	95.57	3.9	29.14	41.24	6.7	22.42
1.2	92.55	91.53	4.0	28.24	40.10	6.8	22.06
1.3	88.83	87.83	4.1	27.38	39.00	6.9	21.71
1.4	85.12	84.46	4.2	26.56	37.96	7.0	21.38
1.5	81.40	81.37	4.3	25.77	36.97	7.1	21.06
1.6	77.68	78.55	4.4	25.03	36.03	7.2	20.75
1.7	73.96	75.97	4.5	24.34	35.13	7.3	20.45
1.8	70.25	73.60	4.6	23.69	34.26	7.4	20.16
1.9	66.54	71.41	4.7	23.07	33.41	7.5	19.88
2.0	63.21	69.37	4.8	22.48	32.59	7.6	19.61
2.1	60.20	67.47	4.9	21.92	31.82	7.7	19.34
2.2	57.48	65.67	5.0	21.38	31.11	7.8	19.08
2.3	54.97	63.94	5.1	20.87	30.42	7.9	18.82
2.4	52.68	62.22	5.2	20.37	29.75	8.0	18.57
2.5	50.42	60.55	5.3	19.89	29.10	8.1	18.33
2.6	48.16	58.92	5.4	19.43	28.48	8.2	18.09
2.7	46.08	57.33	5.5	18.99	27.87	8.3	17.86
2.8	44.10	55.78	5.6		27.33	8.4	17.64
2.9	42.29	54.26	5.7		26.81	8.5	17.43
3.0	40.57	52.79	5.8		26.30	8.6	17.22
3.1	38.95	51.33	5.9		25.81	8.7	17.01
3.2	37.42	49.91	6.0		25.34	8.8	16.82
3.3	35.98	48.55	6.1		24.88	8.9	16.63
3.4	34.66	47.24	6.2		24.01	9.0	16.45
3.5	33.53	45.97					

(*b*) FOR SIMPLE LOCOMOTIVES USING SUPERHEATED STEAM

Velocity, *M*.	Per cent.	Velocity, *M*.	Per cent.	Velocity, *M*.	Per cent.	Velocity, *M*.	Per cent.
Start	106.00	2.7	47.12	4.5	31.19	6.3	22.90
0.5	103.00	2.8	45.82	4.6	30.61	6.4	22.56
1.0	100.00	2.9	44.61	4.7	30.05	6.5	22.21
1.1	92.42	3.0	43.49	4.8	29.52	6.6	21.89
1.2	86.55	3.1	42.30	4.9	29.00	6.7	21.57
1.3	81.20	3.2	41.21	5.0	28.48	6.8	21.24
1.4	76.95	3.3	40.17	5.1	27.96	6.9	20.92
1.5	73.00	3.4	39.22	5.2	27.47	7.0	20.62
1.6	69.55	3.5	38.30	5.3	27.00	7.1	20.32
1.7	66.60	3.6	37.42	5.4	26.53	7.2	20.07
1.8	63.66	3.7	36.61	5.5	26.10	7.3	19.78
1.9	61.27	3.8	35.89	5.6	25.69	7.4	19.52
2.0	58.96	3.9	35.11	5.7	25.26	7.5	19.26
2.1	56.94	4.0	34.39	5.8	24.86	7.6	19.01
2.2	55.12	4.1	33.72	5.9	24.46	7.7	18.76
2.3	53.26	4.2	33.06	6.0	24.04	7.8	18.52
2.4	51.53	4.3	32.40	6.1	23.66	7.9	18.28
2.5	49.98	4.4	31.79	6.2	23.28	8.0	18.06
2.6	48.50						

$33\times\frac{56}{336.13}=5.5$ M.P.H.; 22 M.P.H is 4.0 M. From Table XVIII 23.87 lb. steam per I.H.P. are required for 4.0 M velocity. $328\times\frac{60}{23.87}=822$, the I.H.P. at 22 M.P.H. The cylinder tractive power $=822\times\frac{375}{22}=14{,}000$ lbs. The total resistance of engine and tender $=18.7\times88+80\times4+2.6\times164.5+20\times5+.25\times484=1132$ lbs. Hence the drawbar pull is $14{,}000-1132=12{,}868$ lbs. at 22 M.P.H.

Tractive Effort. The tractive effort of a locomotive is greatest at starting, decreasing slowly to the maximum velocity at which full cut-off can be maintained, about 7 to 10 M.P.H., and then falling off more rapidly for higher speeds. This fact is due to the inability to supply steam to the cylinders at the rate required by the larger number of strokes per minute. The drawbar pull times the distance passed over gives the work done by the locomotive and this product divided by the time gives the horsepower of the locomotive, or

tractive effort.

$$\text{Drawbar pull in pounds}=\frac{\text{h.p.}\times33000\times60}{V\times5280}$$

$$=\frac{375\ \text{h.p.}}{V}$$

where h.p is the horsepower of the locomotive
and V is the velocity in miles per hour.

tractive effort

From this equation, it is evident that with a given horsepower, the drawbar pull varies inversely with the speed. A theoretical graph of this equation would be an equilateral hyperbola; Fig. 11 shows the actual rate of reduction of an Atlantic type locomotive, weighing 96½ tons, 54 tons on drivers, cylinders 21½ by 26, boiler pressure 180 lbs., drivers 79 in. The maximum horsepower is usually exerted at about 700 ft. per minute piston travel and a practically constant horsepower from 700 to 1000 ft. per minute. The tractive power in terms of the speed is given as

$$T=d^2P\frac{L}{D}\left(0.95-\frac{392L}{11000D}V\right)$$

L = the stroke in inches;
D = diameter of drivers in inches;
P = boiler pressure in pounds per square inch;
V = velocity in miles per hour;
d = diameter of cylinders in inches.

By plotting the total resistance curve at the bottom of the sheet showing tractive effort, the maximum speed at which the locomotive can continue to accelerate its train can be determined. The tractive force available for accelerating the train at any speed is the difference between the ordinates to the two curves.

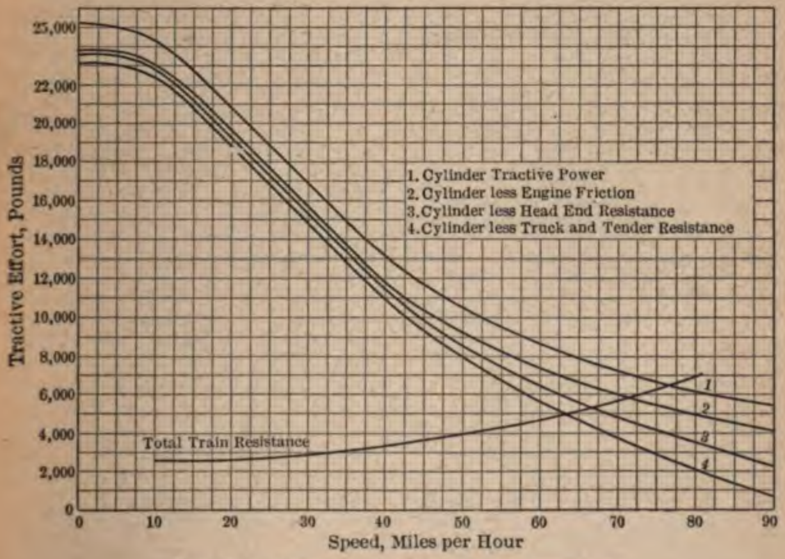

FIG. 11.—Tractive Effort of a Locomotive.

The tractive effort at any speed is sometimes calculated by the formula, $T=\frac{0.85Pd^2L}{D}\times$speed factor. This speed factor diminishes with the speed and is dependent upon the type and characteristics of the locomotive. The theoretical tractive effort for a four-cylinder compound locomotive at starting is, according to the Baldwin formula, $T=\frac{PL}{D}(0.66d_1{}^2+0.25d_2{}^2)$, where d_1 and d_2 are the diameters of the high and the low cylinders respectively.

This pull may be increased 15 per cent when high pressure steam is admitted directly to all cylinders.

The tractive effort of a locomotive is necessarily limited by the adhesion of the wheels to the rails. The coefficient of friction between the steel wheels and the steel rails is such that the adhesion factor is usually taken as one-fourth. Under normal conditions it is about 0.22 to 0.25, is much less on slippery rail, and may be temporarily increased to about 0.35 by the use of sand.

Economy of Large Locomotives. The notable increase in train loads within recent years has caused railroads generally to build heavier locomotives. The cost of handling a certain amount of traffic is in general much decreased with a decrease in the number of trains required to haul it. The operating expenses involved in transporting a given amount of freight might be expressed by an equation in a general form thus,

$$O=K+CM^x,$$

O being the operating expenses, K a constant, M the train mileage, and x a constant exponent. This fact has led to the introduction of the Mikado and Mallet types of locomotives. The figures given below indicate the economies effected on certain roads by the use of Mikado (2–8–2) locomotives having a drawbar pull of 60,000 lbs. over the Consolidation type (2–8–0) having a tractive effort of 41,000 lbs.

Roads.	D., L. & W.	Erie.	C. & A.	B., R. & P.
	Per cent.	Per cent.	Per cent.	Per cent.
Increase in train loads	14.0	27.0	27.4	17.7
Decrease in coal per trip	20.0	12.5	17.8	6.7
Decrease in water per trip	17.0	3.0	16.1	7.0
Decrease in coal per ton-mile	32.4	30.9	35.5	20.2
Decrease in water per ton-mile	27.2	24.7	34.2	22.2

The engine expenses are very little greater for heavy locomotives than for light, and the destructive effect on track and track structures is not materially greater, hence the saving on account of decreased train mileage is very marked. With the adoption of more powerful locomotives, lighter grades become economical, hence this topic will be considered further under the subject of gradients.

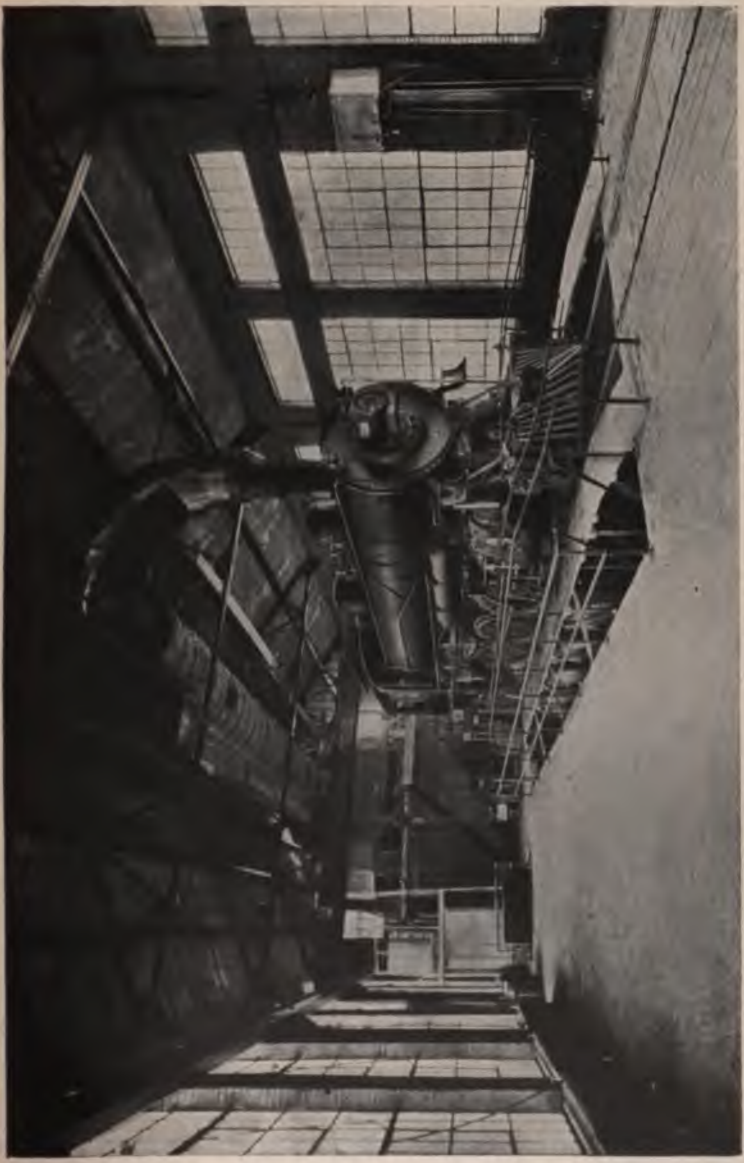

FIG. 12.—Locomotive Testing Laboratory at the University of Illinois.

Locomotive Testing. The first locomotive testing plant was established at Purdue University in 1891, but since that time there have been about five others established, among which are the ones located at the University of Illinois, the Pennsylvania shops at Altoona, at Iowa State College, and at St. Louis. The testing of locomotives has had an effect on locomotive design similar to that of the Holyoke testing plant on hydraulic turbines.

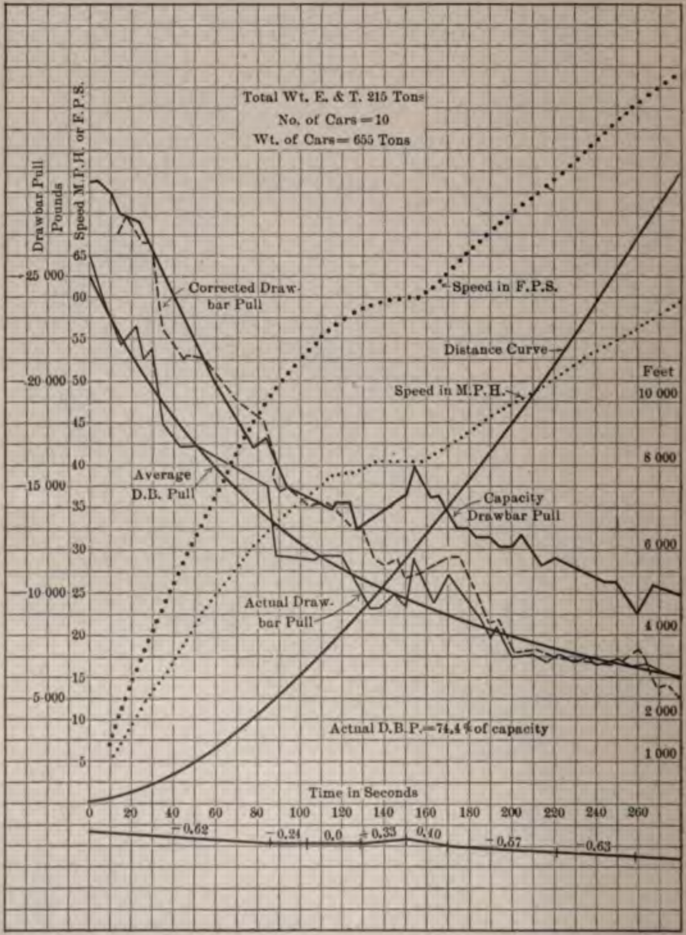

FIG. 13.—Drawbar Pull During Acceleration.

The laboratory methods developed in these testing plants has led to more accurate and reliable service tests, and these together with the results obtained directly in the laboratory have stimulated marked improvement in locomotive design.

The tests are made after the manner of testing a stationary steam plant. Facilities are arranged for testing and weighing the coal used, weighing and analyzing the ash, weighing the amount of water consumed, and for determining the amount of steam used. Also records are made of spark losses, the temperature of flue gases, etc. The apparatus consists essentially of (1) supporting wheels on axles running in fixed bearings on which the locomotive rests and which serve as trunnions on which the locomotive wheels turn, (2) Prony brakes on the axles of the supporting wheels which absorb continuously the work done by the locomotive, (3) a traction dynamometer which, while

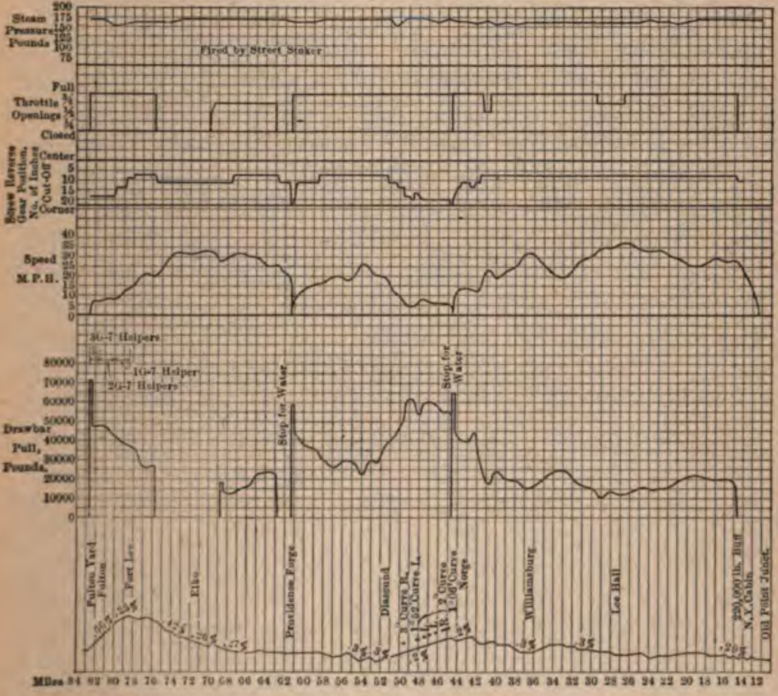

FIG. 14.—Drawbar Performance under Running Conditions.

holding the locomotive practically rigid, measures the horizontal pulling force. The positions of the supporting wheels are adjustable so that various spacings of drivers may be readily accommodated. The locomotive is run on the supporting wheels by extending the track, allowing the weight to rest on the flanges of the wheels, and subsequently removing the rails, thus allowing the weight to come upon the supporting wheels. Fig. 12 shows a view of a locomotive ready to be tested in the laboratory of the University of Illinois.

Much valuable information has been obtained from this sort of tests, particularly in regard to rate of heat radiation, relation between speed and drawbar pull, spark losses, etc.

By attaching a dynamometer car between the tender and the train, the drawbar pull of the locomotive under various conditions of operation can be observed. A regularly fitted dynamometer car contains recording devices for observing all factors that may enter into train resistance as well as the drawbar pull. Fig. 13* shows the results of observations on a Pacific locomotive in accelerating its train on a comparatively level profile and Fig. 14 illustrated the performance of a Mikado locomotive over a varied profile of considerable length with a train load of 7590 tons.

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* Locomotive Operation and Train Control, A. J. Wood, p. 41.

See "General Electric Review" Sept. 19
Page 723 - #9 Vol. 23.

CHAPTER IX

ELECTRIC TRACTION

Introduction. Because of the rapid development of interurban electric railroads, the electrification of portions or the whole of steam trunk line railways, and the electrification of terminals, and the important place that electric traction will take in future railways, it seems necessary to consider briefly the performance of electric motors when applied as motive power for railway operation. Under certain conditions, which will be mentioned later, electric traction has decided advantages over steam locomotives, and as these advantages become better understood, electrification will probably be employed to a greater extent than at present. However, at the present state of development electric motive power has not been proved superior to steam for all conditions, and the failure to electrify steam roads generally has a more rational basis than the conservatism of managing officers. It is manifestly impossible to consider in this connection the many phases of electric traction, consequently the discussion will be limited to a very brief statement of a few facts related to the subject of railway location.

Conditions Favorable for Electric Traction. In the early development of railways, there was much difference of opinion as to whether locomotives should be used for motive power, or whether stationary engines should be employed, it being proposed to place the latter at comparatively short intervals and to draw the trains by means of cables from the stationary power plants. Electric traction, in a way, goes back to that primitive scheme in that large stationary plants are used in generating power, but electricity instead of cables is used to convey the power to the train.

The characteristic features of electric traction when used to operate a railway as compared to steam traction are:

1. Large increase in initial investment due to cost of power plant and transmission lines and more costly rolling stock. This condition results in heavy fixed charges.

2. Economy in fuel consumption and in engine expenses.

3. Higher speed can be maintained with heavy trains on account of the large drawbar pull at high speeds, with resulting increased capacity of the road.

The above briefly stated facts would indicate that very busy railroads carrying heavy traffic where the full capacity of the power plant and transmission lines could be utilized nearly uniformly all the time, electric traction may present opportunities for economy, but for light traffic railways, where the capacity of the plant cannot be used all the time, the fixed charges would more than counterbalance any economies that might be effected in operating expenses. The one great advantage resulting from electrification is increased capacity of the railroad, and unless the traffic is at hand to be transported electric traction will not, in general, be found economical. With steam locomotives, each unit is operated as the need requires, consequently the service is much more elastic than with electric traction.

Electric traction is clearly desirable, then, for roads having many trains with frequent stops, such as elevated and rapid transit railways in cities, and for roads where power is cheaply available at one point, as from hydro-electric plants. It is not economical, in general, for trunk lines operating under normal conditions of traffic nor on branch lines.

Sometimes other considerations than economy enter to make electric traction desirable, such as to avoid smoke in busy terminals in large cities and to afford better ventilation on tunnel lines.

In cases where increased capacity is necessary and can only be accomplished by a large outlay in grade reduction and line improvement, electrification may offer a more economical means of securing the required increase in capacity.

Advantages and Disadvantages of Electric Traction. The following advantages of electric traction as applied to railways may be mentioned:

1. Comfort of passengers increased due to greater cleanliness and better ventilation.

2. Higher speeds can be maintained with efficient operation.

3. More frequent service owing to necessity of as nearly constant draft on the power plant as possible.

4. Economy in fuel because of greater efficiency at station-

ary power plant in the consumption of fuel. An ordinary steam locomotive consumes approximately 5 lbs. of coal per horsepower hour while the stationary plant consumes about 3 lbs. However, improved locomotives with the brick arch are said to have reduced fuel consumption to less than 5 lbs. per horsepower hour. On the Manhattan Elevated Railway, the fuel consumption per unit of traffic was reported 70 per cent greater with steam locomotives than with electric traction. Moreover, a lower grade of coal can be used in the well-arranged stationary plant than on locomotives. However, a considerable portion of this greater efficiency in the consumption of fuel is not realized at the drawbar because of transmission losses. Perhaps an economy of 10 to 15 per cent in fuel consumption may be realized at the drawbar under favorable conditions.

5. More satisfactory control of trains because of improved brakes and more ready control of power.

6. Decreased cost of engine repairs, amounting to 18 per cent on the New York Central at New York * and about 33 per cent on the Pennsylvania at the same place.

7. Decrease in wages of train crews.

8. Increased ton-mileage per locomotive per year owing to the greater rapidity of movement of electric locomotives, amounting to 25 per cent on the New York Central.* This results also from decreased detentions on account of the locomotive repairs and not stopping for fuel or water.

9. Decreased dead ton-mileage owing to larger proportion of weight of locomotives on drivers. Where motors are on the axles of the cars, the dead ton-mileage is reduced to a minimum.

Some of the disadvantages of electric traction are:

1. High initial cost of installation with the accompanying high fixed charges, including

   a. Cost of the power plant.

   b. Cost of transmission line, both first cost and maintenance.

   c. Increased cost of locomotives, a steam locomotive costing about $25,000 and an electric locomotive about $45,000.

   d. For existing roads, the loss due to change of facilities for caring for locomotives.

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* Proc. A.I.E.E., Vol. XXVI, p. 1776.

2. The losses of transmission of power from the power plant to train.

3. The difficulties incident to the transmission of power because of storms, etc.

4. For light traffic or moderate traffic railroads, the total cost of operation per traffic unit is higher than with steam locomotives. On the Annapolis Short Line, the cost per car-mile was 28.5 cents with electric locomotives as against 23.1 cents with steam locomotives before electrification, making a difference in operating costs of 5.4 cents per car-mile. When fixed charges were considered, the total cost was about 16.6 cents per car-mile more under electric than under steam traction.*

Motors. The function of the motor is to receive the electric energy from the distributing line and to convert it into drawbar pull at the desired speed. The motor is the essential element so far as performance and other questions that may affect alignment and grades are concerned. Almost any tractive power desired can be obtained by the use of a sufficient number and large enough motors, and frequently questions of location, such as gradient, resolve themselves into choosing heavier motors or spending more money in improving the line.

Motors for traction service may be classified as follows:

A. Direct Current
  1. Series
  2. Shunt
  3. Compound

B. Alternating Current
  I. Polyphase
    1. Induction
    2. Synchronous
  II. Single phase
    1. Series
    2. Induction
    3. Synchronous
    4. Repulsion.

Direct-current motors have been used from the beginning of electric traction, usually operating on about 600 volts, the potential between the contact line and the rail being usually 550 to 660 volts, although 1200 volts and even 2400 volts have been used to some extent. The higher voltage has advantages for heavy traction.

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* Proc. A.I.E.E., Vol. XXVII, p. 1166.

The series motor, either direct or alternating current, has been quite generally used for railroad work owing to the fact that it has a strong starting torque, or high tractive effort at starting. The tractive effort of series motors falls off rapidly as the speed increases, varying almost inversely as the speed. For most conditions such a motor meets the need because the demand for drawbar pull decreases with the speed under normal conditions. The chief objection to the series motor of the direct-current type is the expense of the distributing system.

The three-phase induction motor is essentially a constant-speed motor, variations of speed being accomplished only by methods that are wasteful of power. The speed of synchronous motors is directly proportional to the frequency of the impressed electro-motive force and inversely to the number of poles, being independent of the load.

The repulsion motor is similar in construction to the single-phase series motor and has a good starting torque.

The efficiency of a three-phase motor is high, higher than is generally obtained from other types, being about 91 per cent as against 90 and 87 per cent for direct-current and single-phase motors respectively. With three-phase motors, current can be conveniently restored to the line by electric breaking. The chief disadvantages of this type of motor are (1), it is essentially a one-speed machine, (2) starting torque is low and efficiency at starting are low, (3) the torque varies as the square of the impressed voltage, consequently variations in line losses greatly affect the operation.

Power of Motors. The power of electric motors is usually expressed in terms of kilowatts, 0.746 kilowatt being equivalent to one horsepower. The power of a motor is the rate at which it transforms electrical energy into mechanical energy and is measured by the product of the electro-motive force and the current in the case of direct-current motors, and this quantity times the power factor for alternating-current motors. The power factor is the cosine of the angle of phase between the electro-motive force and the current in the case of alternating currents, and is usually about 0.85 for three-phase current, although this may be slightly increased for railway work.

Since it is impractical to build motors which will operate at as low a speed as the driving wheels, it being therefore not desirable to attach the motors directly to the axles of the drivers it is necessary to introduce a single reduction gearing between the motor shaft and the driving axle. The gear ratio is the ratio between the number of teeth in the gear and the number of teeth in the pinion, or is, in general, the ratio between the speed of the motor shaft and that of the driver axle. Obviously, the speed of the car varies inversely and the tractive effort varies directly with the gear ratio. In Fig. 15* is shown typical characteristic curves of a direct-current motor, having an output of 65 horsepower at 95 amperes, 600 volts, with a gear ratio of 3.52.

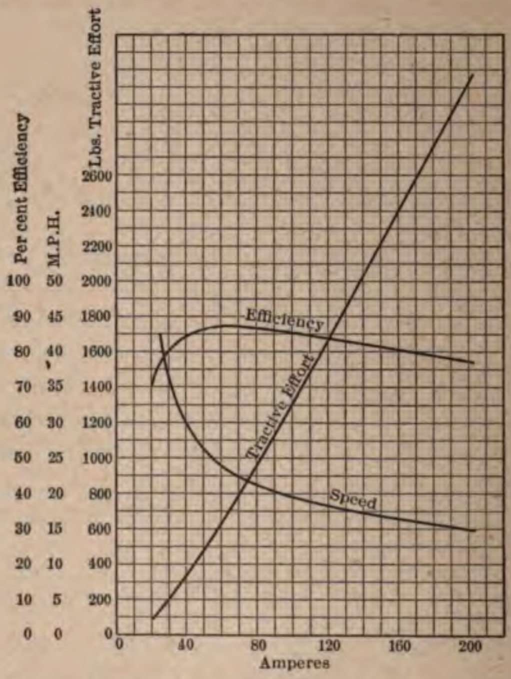

FIG. 15.—Typical Railway Motor Characteristic

Motor Rating. Owing to the variableness of the service required of railway motors, they are rated somewhat differently from other electric machinery. A motor is said to have a certain horsepower capacity if it will develop that horsepower continuously for one hour with a temperature rise of 75° C. above the surrounding air, the surrounding air not exceeding 25° C. This method of rating, although arbitrary, has been in use for a number of years, and while not giving necessarily the exact capacity of a motor for all classes of service, is a convenient measure of capacity and furnishes an idea of the relative sizes of motors. The heating of a motor in service depends upon the nature of the service, such as weight of train, schedule speed, number and duration of stops, profile and alignment of road, and the potential of the line.

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* Bulletin 4173 General Electric Co.

Owing to the fact that the insulation of a motor deteriorates rapidly if heated above a certain temperature, sometimes a momentary and a continuous rating are given to electric motors for traction service. It requires a considerable time for motors to reach the temperature at which the insulation is damaged, hence the temporary or starting rating may be greater than the hour rating, and the continuous rating may be somewhat less than the hour rating, the continuous rating being the output which motors can give continuously without injurious heating. In the earlier locomotives no attention was paid to the continuous rating, the service being of an intermittent character, the runs between stops being short, hence chief stress was laid on the starting and accelerating tractive capacity. With the extension of electrified lines it was found necessary for the locomotive to deliver a continuous output for long periods of time, and as result air-ventilated motors were introduced with fireproof

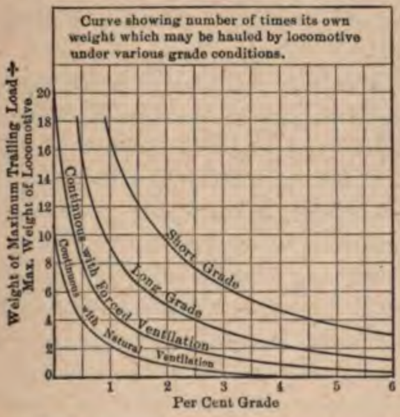

FIG. 16.—Performance of Electric Motors on Grades.

insulation in order to keep the size of the motors within the limits of the rolling stock, and the rating is commonly given on a continuous basis.

Because of the heating of the motors when subjected to heavy load for a long period of time, electric locomotives cannot be given so high a rating over long, heavy grades as over a more choppy profile. This condition is illustrated in Fig. 16, which shows the ratio of the trailing load to the weight of the locomotive for grades of different lengths. "Short grades" would represent an occasional grade of 2000 ft. or less in length with ample time for cooling of the motors between grades. Where long grades, i.e., two to three miles in length, are encountered, the rating is necessarily decreased, and for continuous grade conditions it must be still further reduced.

Electric Locomotives. For freight hauling both on electrified lines and on industrial railways, electric locomotives are used, and they are coming into use for passenger service to some extent, especially on electrified districts of steam railways. Steam locomotives are primary energy generators, whereas electric locomotives merely apply the energy delivered to them from the power plant. Steam locomotives are subject to certain limitations in regard to their ability to generate power and to other limitations in regard to their ability to apply to traction the power that they generate; electric locomotives are subject to limitations in regard to converting energy and to the same limitations as the steam locomotive in regard to applying the power to traction. The power of a steam locomotive is limited chiefly by the steaming capacity of the boiler, while an electric locomotive may be built to convert electrical to mechanical energy at an almost unlimited rate, for, each axle being supplied with a motor, it is only necessary to provide enough axles and the tractive power may be increased almost indefinitely.

Electric locomotives are as yet in the developmental stage to a great extent and have not reached that standardization of design that is characteristic of steam locomotives, and they still lack much in definiteness of design and performance that is possessed by the latter. Not only electrical problems are to be solved in the design of the motor, etc., but the mechanical design of the framework and arrangement of machinery constitute a difficult problem. For example, too low center of gravity and too rigid frame are elements that are sure to make the electric locomotive ride the track badly and also to be hard on the track. So far as the mechanical arrangement is concerned, experience has shown the more nearly the design is similar to that of the steam locomotive, the more satisfactorily the locomotive will ride the track. The Pennsylvania R. R. electric locomotives have even retained the connecting rod and side bar in order to make the distribution of weight and the action similar to the corresponding features of the steam locomotive.

The main characteristics of electric locomotives that affect railway location directly are:

1. Their ability to exert full drawbar pull up to high speeds enables them to have a greater transporting capacity per locomotive.

2. The limiting factor, aside from the driving mechanism, of an electric locomotive is that it must lose only such power in the motor in the general average as to keep it within safe heating limits.

3. The electric locomotive is most efficient generally at comparatively high speeds, and hence, its economical speed is higher than for steam locomotives. To realize the economies possible by electrification, therefore, operating methods must be altered so as to take advantage of the maximum efficiency conditions of the electric locomotive.

4. Somewhat greater adhesion to the rails is said to be obtained owing to the constant torque of the motors and also because of the greater proportion of weight on the drivers.

Perhaps the most recent type of electric locomotive construction for trunk line service is that used by the C., M. & St. P. Ry. on the electrification of its line from Harlowtown, Mont., to Avery, Idaho, a distance of 440 miles. This locomotive with a gear ratio of 2.45 is used for passenger service and with a gear ratio of 4.56 for freight service. The drawbar pull is 72,000 lbs. for the operating speed of $15\frac{3}{4}$ M.P.H.

A similar locomotive used on the Norfolk and Western Ry. with a total weight of 440,000 lbs., 400,000 being on the drivers, has a tractive effort of 114,000 lbs. at starting and 86,000 lbs. at 14 M.P.H. On a test, it actually developed a pull of 170,000 lbs.*

The gearless type of locomotive used by the New York Central

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* Journal W. Soc. Eng., Apr., 1915.

Ry. has a high mechanical efficiency (93 per cent), but operates at maximum efficiency at 50 to 60 M.P.H., and hence is best adapted for service over an easy profile.

The electric locomotives * for use in the tunnels of the Pennsylvania R. R. at New York were designed to accelerate a train of 550 tons on a 1.93 per cent grade in the tunnels. In actual operation they frequently start 850 tons on this grade, and trains weighing over 1000 tons are handled without difficulty. Each locomotive is run over an inspection pit once in 24 hours, and after running 3000 miles it is taken into the shops for complete inspection and adjustment. It is taken into the shops for general repairs after about 90,000 to 112,000 miles. After 33 locomotives had been in use for four years, the detention record was as follows:

Locomotive-miles	3,947,746
Total engine failures	45
Total minutes detention to trains	271
Locomotive-miles per minute detention	14,667

The C., M. & St. P. Ry. made a series of tests in November, 1915, which gave interesting results. The locomotive weighing 284 tons took an ore train with 4660 tons trailing load down a 1.0 per cent grade at a maximum speed of 25 M.P.H., reducing to 16 M.P.H. on a heavy curve and to a miminum of 7 M.P.H. Regenerative braking was applied returning 21 per cent of the current to the line at 2200 volts, equivalent to 52.5 per cent at 3000 volts at which the locomotive is supposed to operate. The locomotive took the same train up a 0.4 per cent grade at the low voltage. (The test was run on the 2200 volt line of the B., A. & P. R. R., the power not being available on the C., M. & St. P. line.)

The characteristics of two common types of electric locomotives are shown in Fig. 17. (*a*) represents a 0–6–6–0 type of locomotive, weighing 151 tons, used for heavy mountain grades. It has a gear reduction of 4.36, has a rated tractive effort of 41,000 lbs. at 11 M.P.H. at 600 volts with 1700 amperes. (*b*) is the gearless 2–8–2 type, weighing 100 tons, and used for fast passenger service on the N. Y., N. H. & H. R. R. With 3050 amperes at 600 volts, it has a rated tractive effort of 20,500 lbs. at 40 M.P.H.

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* *Ry. Age Gazette*, Sept. 17, 1915.

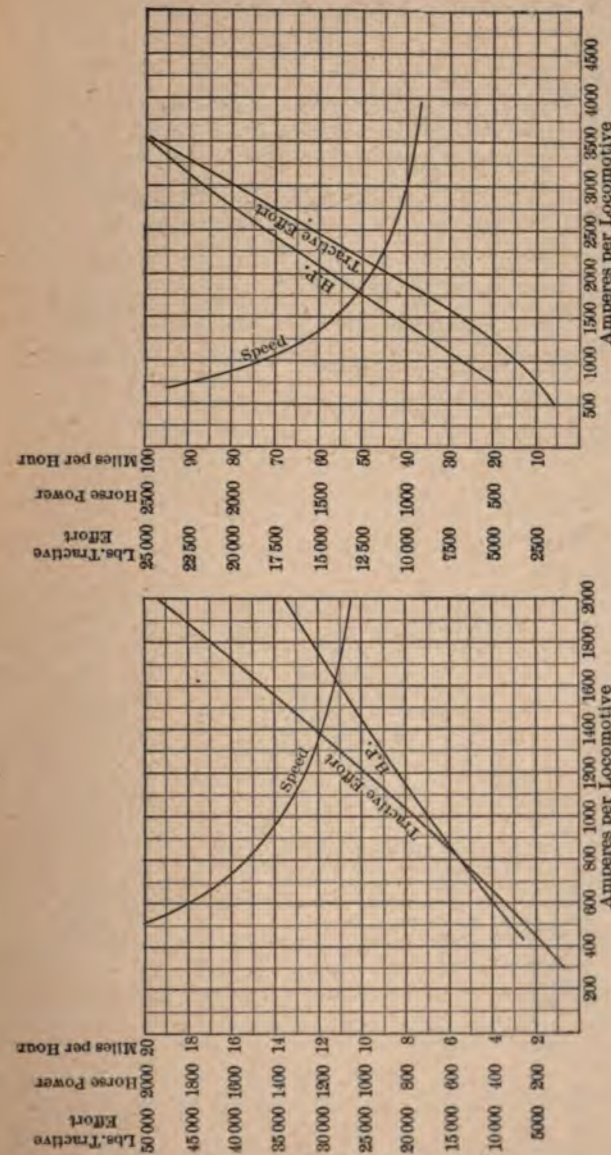
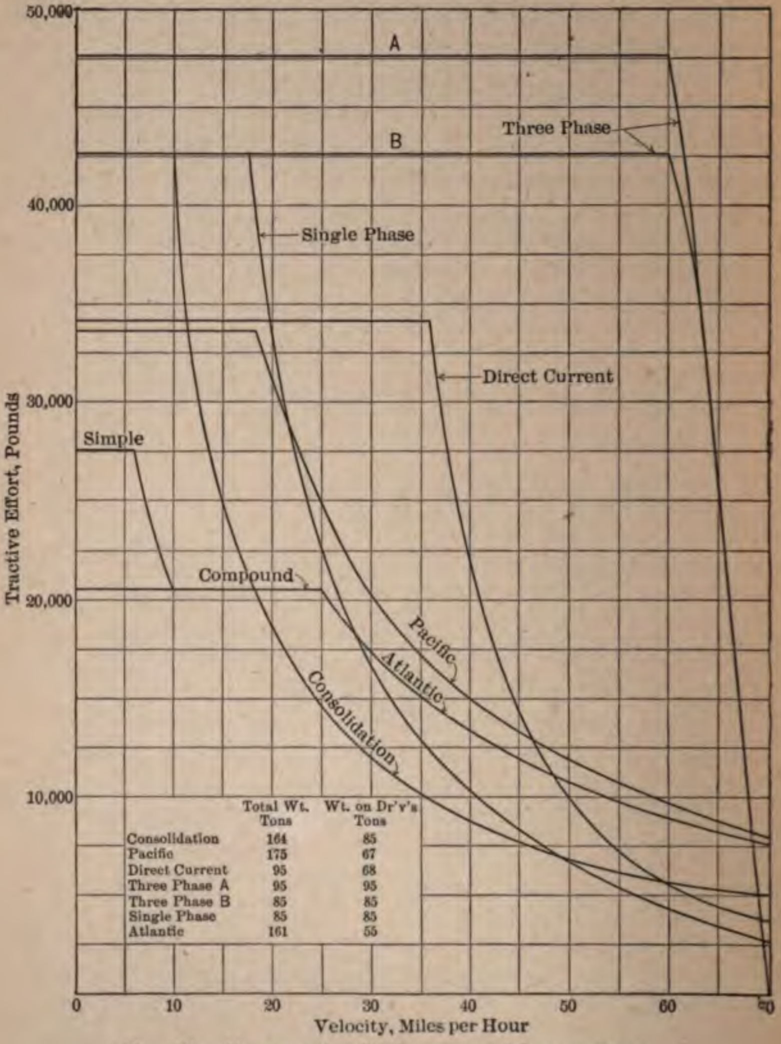


FIG. 17.—Characteristics of Electric Locomotives

Comparative Performance. Of the various types of motive power, both steam and electric, that may be used in railway work, each has characteristics that fit it for some particular class of service, and these characteristics should be studied in connection with a proposed revision of line or grade of a railroad and in



	Total Wt. Tons	Wt. on Dr'v's Tons
Consolidation	164	85
Pacific	175	67
Direct Current	95	68
Three Phase A	95	95
Three Phase B	85	85
Single Phase	85	85
Atlantic	161	55

Fig. 18.—Comparative Performance of Locomotives.

connection with a proposed location. Fig. 18 taken from a paper by Mr. C. L. Muralt,* shows the comparative performance characteristics of various types of locomotives, including the New York Central direct current, the N. Y., N. H. & H. single, phase alternating current, two three-phase alternating current, a Pacific type of steam locomotive of the Southern Pacific Ry., and Atlantic type of the New York Central and a consolidation type of the Delaware and Hudson Ry. All of these curves begin at a point corresponding to the maximum tractive effort obtainable by adhesion.

Electrification doubtless will be used more and more in the solution of transportation problems in the future and it is important that railway engineers should appreciate its possibilities.

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* Proc. A. I. E. E., 1908, p. 115.

CHAPTER X

ROLLING STOCK AS AFFECTING ROADWAY

Introduction. That the character of the service to be rendered and the weight and capacity of rolling stock to be used will have a direct and important bearing upon the choice of alignment and the treatment of gradients and curvature is obvious. The increased size of freight and passenger cars, the improved draft gear and the recent developments in the air brake have modified to a considerable extent the results to be striven for in railroad location. The operation over grades and around curves have been influenced by the two last items especially. The increase in the pay load as compared with the tare weight of cars made possible by the use of high capacity cars as well as the resulting increased train load are matters of importance in this connection. The length, rigidity, flexibility and other physical properties of trains that may affect their behavior as they pass over the line have a decided influence on the problem of location.

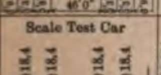
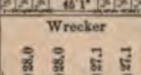
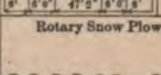
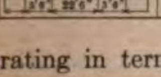
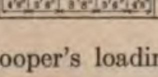
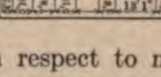
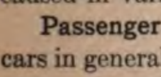
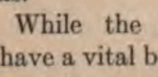
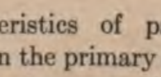
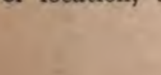
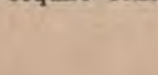
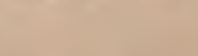
Freight Cars. The average capacity of freight cars ("goods wagons") in England is about 8 or 10 tons and in Germany they average 14 tons. These small sizes of freight cars are well adapted to the quick delivery freight service of those countries. About 1880 the capacity of freight cars in America was 10 to 15 tons, and it was not until comparatively recent years that railway managers began to appreciate the economy of the large capacity cars, especially as applied to through car-load service. Statistics of the Interstate Commerce Commission show that the number of freight cars in the United States increased from 1,550,000 in 1902 to 2,260,000 in 1913, and that the average capacity increased in the same period from 28 tons to 39.1 tons, representing an increase of 46.4 per cent in number and 39.7 per cent in capacity. In 1913 the average capacity of freight cars was as follows:

	Tons.
Box cars	35
Flat	33
Stock	30
Coal	42
Tank	39
Refrigerator	32
Other cars	39

The ratio of the pay load of cars to their dead weight has greatly increased with the capacity of the cars. In 1880, the 25-ton car had a dead weight of 12.5 tons, which made the ratio of capacity to dead weight 1 : 2. The modern 100,000 lb. capacity car weighs about 37,500 lbs., making a ratio of dead weight to capacity of 1 : 2.7.

Table XX shows the weights and principal dimensions of freight cars of the C., M. & St. P. Ry. and Fig. 19 shows their rating in terms of Cooper's loadings with respect to moments caused in various spans.

TABLE XX
WEIGHTS AND WHEEL SPACINGS OF CARS

Concentrations and Wheel Spacings	Capacity	Light Wt.	Total Wt.	Wheel Base	Length, C'p'l'g	Concentrations and Wheel Spacings	Capacity	Light Wt.	Total Wt.	Wheel Base	Length, C'p'l'g	Concentrations and Wheel Spacings	Capacity	Light Wt.	Total Wt.	Wheel Base	Length, C'p'l'g
41 ft. Gondola 100,000 lb. Cap. 	110,000	41,500	151,500	37'10"	45'9"	21 ft. Ore Car 100,000 lb. Cap. 	110,000	30,600	140,600	19'6¾"	24'0"	42 ft. Box 80,000 lb. Cap. 	88,000	40,900	128,900	36'6"	45'0"
30 ft. Hopper 100,000 lb. Cap. 	110,000	38,900	148,900	26'8"	34'3"	44 ft. Express Refrig'r 80,000 lb. Cap. 	88,000	69,875	157,875	38'0"	47'0"	30 ft. Hopper 115,000 lb. Cap. 	126,500	46,000	172,500	28'6"	35'0"
80 ft. Steel Pass. Car 	4,800	155,400	160,200	67'0"	80'6"	80 ft. Wood Sleeper 	4,800	116,300	121,100	66'3"	81'1"	70 ft. G.E. Motor Car 	16,000	100,400	116,400	60'0"	72'0"
Scale Test Car 	100,000	46,780	146,780	33'6"		Wrecker 			220,100	19'8"	29'0"	Rotary Snow Plow 					

Passenger Cars. While the characteristics of passenger cars in general do not have a vital bearing on the primary features of location, they do require consideration in connection with certain minor features such as clearness of side structures, limiting curvature, etc. Passenger cars have greatly increased in weight and length within the past few years. Steel coaches increased in number from 625 in 1909 to 7271 in 1913, or over 1000 per cent, and the change to steel equipment is progressing even more rapidly at the present time. A steel passenger coach costs from $12,000 to $25,000, while a wooden coach of similar dimensions costs from $6000 to $12,000. The weight of a wood coach is about 85,000 to 125,000 lbs. and the weight of a steel coach of corresponding dimensions is about 30 per cent greater. It is estimated that about 15 to 20 per cent more power is required to pull the steel passenger coach than the wooden. Table XX shows the principal dimensions and weights of C., M. & St. P. Ry. passenger coaches and Fig. 19 gives the rating of these in

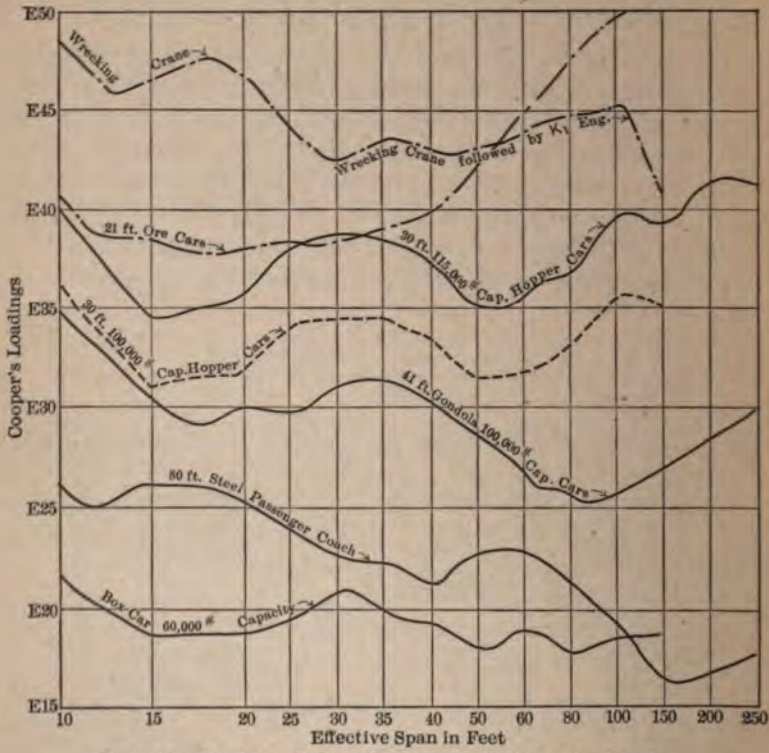


Fig. 19.—Rating of Cars in Terms of Cooper's Loads.

terms of Cooper's loadings for different spans. The maximum width of passenger coaches is about 11 ft. 6 ins.

Economy of Large Cars. Where the volume of traffic and the size of the individual shipment are such as to make it possible to secure full car loads, the large capacity freight car accomplishes a marked economy. However, where light car loads are the rule due to light traffic or to the demand for quick delivery, the smaller cars are decidedly advantageous. The railroads of Germany and England use small cars for their freight traffic, which is essentially of the small order, or retail, nature and thus avoid the half-filled large cars.

The chief economy resulting from the use of high capacity cars lies in the reduction of the length of train, or of the number of trains required to handle a given amount of traffic. These benefits may be stated as follows: *

1. A smaller number of cars is required to transport a given amount of freight. This requires a smaller investment in equipment, less work in the car service department, and decreases the empty car movement in the direction of light traffic. The capacity of the road may be thus increased since, if the maximum number of trains are run, an increase in car capacity causes a proportionate increase in total capacity.

2. A saving in the wages of train and engine crews is effected, since this item varies directly with the number and mileage of trains and not with the tonnage hauled.

3. A saving in repairs to cars and locomotives results due to the stronger construction made necessary in the larger equipment.

4. Larger cars reduce the atmospheric and track resistance per ton of load.

5. They occupy less track space in yards and terminals.

6. Switching charges are reduced owing to the decreased number of cars handled.

Economies resulting from the use of cars having a higher capacity than those now in use are problematical. Owing to the fact that higher capacity would mean greater distance between trucks, and since the stresses in the supporting girders vary as the square of this distance for the same unit loading an increase in capacity would require more than a proportional increase in dead

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* *Railroad Gazette*, May 19, 1905.

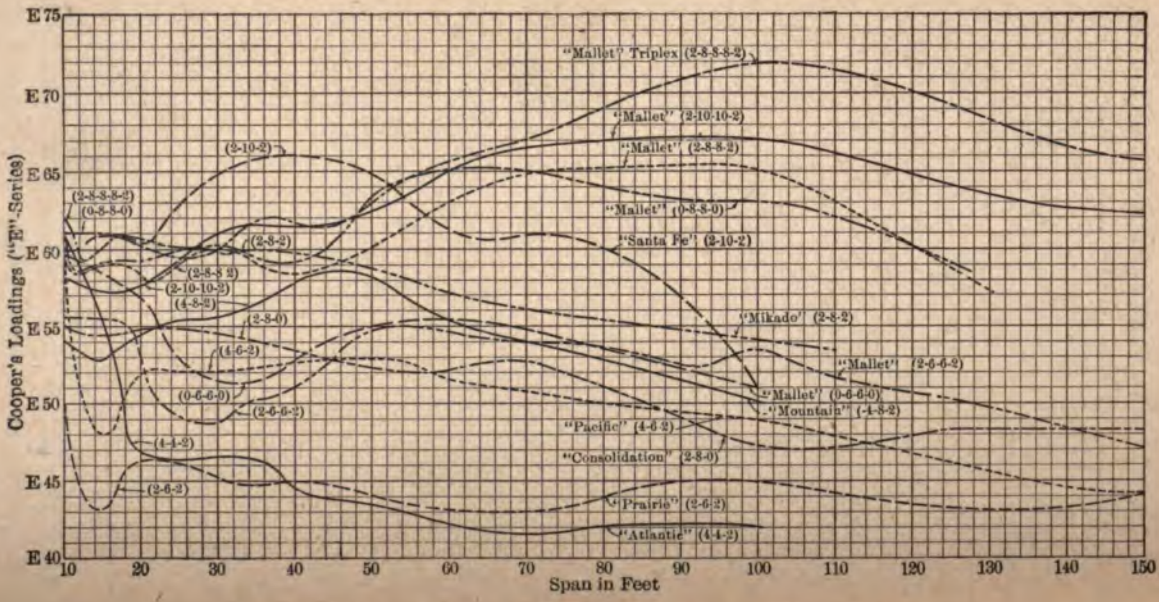
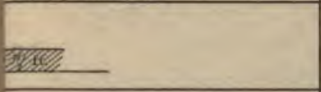
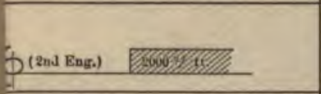
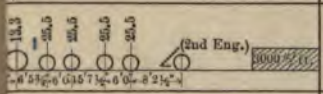
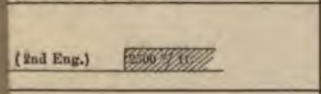
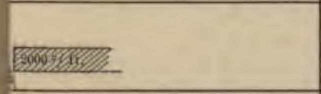
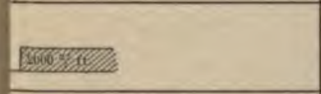
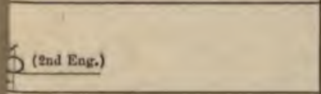
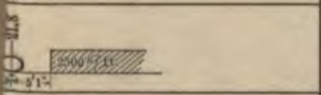
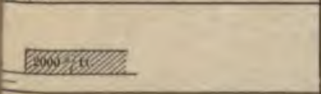
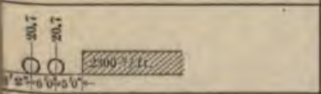
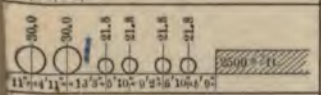
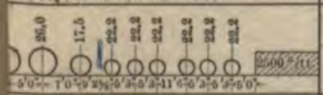
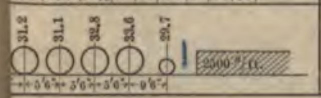


FIG. 20.—Rating of Heavy Locomotives in Terms of Cooper's Loads.

LE XXI

CINGS OF HEAVY LOCOMOTIVES

DIAGRAM nds for One Rail)	WEIGHTS			SERVICE
	ON DRIVERS	TOTAL ENGINE	ENGINE & TENDER	
	Lbs.	Lbs.	Lbs.	
	133,400	231,600	390,000	Fast Pass.
	175,000	248,600	408,600	Heavy Pass.
	499,000	560,000	764,000	Heavy Freight on Mtn. Grade
	231,400	256,000	440,000	Fast Freight
	198,000	317,200	493,200	Heavy Pass.
	239,200	330,000	503,000	Mtn. Pass.
	253,600	332,000	494,400	' Freight
	352,000	352,000	526,000	Freight
	303,000	379,400	577,400	Freight
	327,600	396,200	561,800	Freight
	480,000	480,000	654,000	Hump Switching
	550,000	616,000	882,400	Freight
	761,300	853,000	853,000	Pusher Service

(*To face page 179*)

weight of the car. The wheel concentrations on heavy cars are already so large that a further increase in this respect would hardly seem desirable. Moreover, the cast-iron wheel has about reached its limit in carrying ability, and heavier cars would necessitate the employment of a stronger wheel construction, which would entail great expense. Many other details of construction would have to be modified also with the introduction of materially heavier cars, which would indicate that a further increase in capacity is not imminent.

Weight and Dimensions of Locomotives. While there has been a marked increase in the total weight on the drivers of locomotives in the types that have been developed in this country, the load per axle has apparently reached a stationary quantity approximately owing to the tendency to use a greater number of drivers. It is particularly true that the stresses in track and track structures resulting from wheel concentrations have not greatly increased with the recent types of heavy locomotives. Table XXI * shows the weights and wheel spacings of various heavy locomotives and Fig. 20 shows the ratings of these in terms of Cooper's E-series loadings on the basis of the moments in different bridge spans.

Fig. 21 shows the weight on drivers and the wheel spacings

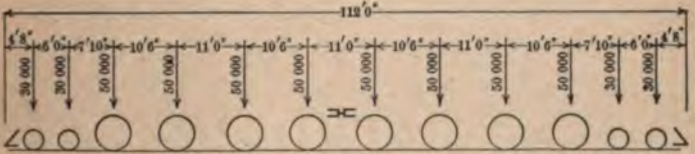


Fig. 21.—Wheel Spacings and Axle Loads of C., M. & St. P. Ry. Electric Locomotive.

of the articulated electric locomotive used by the C., M. & St. P. Ry. over its electrified line in Montana and Idaho.

Draft Gear. The draft gear consists of the mechanism by means of which one car is coupled to another. The growing tendency towards heavier train loads and larger drawbar pull on the more powerful locomotives necessitates stronger and better design of draft gears. The automatic coupler was ordered on all roads doing an interstate business by the Interstate Commerce Commission in 1889, and by their introduction accidents to employees were reduced over 70 per cent. A large proportion of the damage claims on freight is due to the violent jerking and bumping of cars. Live stock and many inanimate articles of freight are injured by rough handling of this sort. Due to the necessary interchange of cars, the Master Car Builders' Association adopted standard general features for draft gear, such as height, universal coupler, etc., but many details are left to the mechanical design of the various railroad shops. The break-in-two accidents of operation which occur frequently on down grades and especially at the bottom of such grades are the result of inadequate draft gear. The following brief description will indicate the development and the present status of draft gear.

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* Proc. Am. Ry. Eng. Assn., Vol. XVI, p. 300.

The *spring draft gear* consists essentially of a yoke to which the coupler is attached and is so arranged as to transmit the load through compressing a spring to one of two "followers," depending on the direction of motion. Although the spring draft gear is still widely used, it has been found lacking in its ability to meet the exigencies of modern traffic.

To provide for this heavier service, the *friction draft gear* has been developed. The principle involved is that of transforming by friction the energy of excessive impact into heat. Springs similar to those mentioned above which have sufficient stiffness to act as ordinary spring draft gears are provided for the usual pushing and pulling of train operation. In 1908 the Southern Pacific Railway made some tests on the Westinghouse friction draft gear which are of interest.* Two trains were equipped for comparative tests, each consisting of fifty oil cars and a dynamometer car. One train was provided with the Southern Pacific tandem spring draft gear and the other with the Westinghouse friction draft gear. A dynamometer car and a slidometer were used for the purpose of obtaining records of shocks from buffs and jerks. The first two tests were to determine the relative amount of slack and recoil in the train. The amount of slack was about the same in the two cases, but the amount of recoil in the train having the spring draft gear was very much greater than in the train equipped with the friction gear, the former being as a maximum 24 ft. or 7.3 in. per car while the latter was only 5 ft. or 1.5 in. per car. The remainder of this very interesting and valuable series of experiments demonstrated that shocks due to jerks and buffs by the friction gear were reduced to a comparatively steady force of about half the maximum force that resulted under the corresponding conditions with the tandem spring gear. One test was made to study the performance under severe conditions produced by rough handling in starting. The train was backed at a speed of 5 miles per hour to gather slack, and when the slack was bunched, the reverse lever was thrown into the forward position, the throttle opened wide, and the rail sanded. The friction draft gear showed jerks from 111,000 to 127,000 lbs., whereas the spring gear showed jerks from 185,000 to 305,000 lbs. In many of these tests, the train equipped with the spring draft gear parted, while in every case the one with the friction draft gear remained intact. These figures doubtless would represent the maximum tensile strains that draft gear could be expected to withstand, although buffing strains might run as high as 500,000 lbs.

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* *Ry. Age Gazette,* Jan. 8, 1909.

Air Brakes. The development of the air brake has had much to do with modern railway operation. By its improvement deceleration may be made much more rapid, the momentum of a down grade can be more safely utilized in mounting another grade, longer and heavier trains can be successfully controlled on down grades, and many other elements of operation have been materially altered thereby. The average running time of trains depends much upon the rate at which they can be brought to a stop, for the average time between the instant when brakes are first applied and when the train finally stops is, of course, half the speed that the train had at the time of application, and the longer the period over which this slackened speed obtains, the greater will be the loss of time for the stop. The loss of time at a stop comprises the loss due to slackened speed during deceleration, the time of standing and the loss of operating at less than full speed during acceleration. Since the time of standing is practically independent of train characteristics, the total time lost will largely depend upon the other two factors. Brakes can decelerate a train much more rapidly in general than the engine can accelerate it, since friction acts only under the engine in the latter case while it is available under the entire weight of the train in the former, and furthermore, the locomotive is pulling against train resistance in the latter case while the brakes act in conjunction with train resistance. The normal rate of deceleration is about 0.7 to 0.8 M.P.H. per second for freight trains and about 1 to 1.5 M.P.H. per second for passenger trains.

The force that really stops a train, of course, is not the friction between the brake shoes and the wheels, for that is internal to the train, but the adhesion of the wheels to the rails is the real retarding force. For this reason, the highest possible retarding force results when the friction force between the brake shoes and the wheels is slightly less than sufficient to slide the wheels, for as is well known, the coefficients of sliding friction is less than the coefficient of static friction. The braking power is stated in a scale of percentages, wherein 100 per cent represents a brake shoe pressure on each wheel equal to the pressure of that wheel on the rail; thus 85 per cent braking power means that the pressure between the brake shoe and the wheel is 85 per cent of that between the wheel and the rail. Obviously, for any given arrangement of brakes, the braking power would not be the same for loaded as for empty cars. In order that the wheels may not skid, the braking power is usually fixed in terms of the weight of the cars when empty, although both "light and load" brakes are available to suit either condition.

It is needless for present purposes to attempt a minute description of the mechanism of an air brake, since the results accomplished constitute the information needed by the engineer when studying location problems. Suffice it to say, therefore, that with the automatic brake on connected cars, a pipe runs through the train, the pipe being charged with air from the locomotive and in communication with a triple valve under each car, and that in turn, with an auxiliary storage reservoir which is charged with compressed air for braking the car on which it is carried. This, in turn, operates the air-brake cylinder whenever the engineman applies the air. The air in the pipe actually holds the air piston in balance and the brakes from the wheels, so that if an accident ruptures the air pipe, thereby permitting the air to escape, the higher pressure of the auxiliary air cylinder then acts upon the piston and applies the brake. This is the form known as the automatic brake, and, although it is a marked improvement over the old type of air brake, it still lacks rapidity and uniformity of application. The " quick-action " brake added a method of venting the air under each car and thus secured a rapid and uniform application of the brakes. The invention of the electro-pneumatic brake has now displaced all older forms in certain classes of service because the action is simultaneous throughout the length of the train. In interurban and other electric railway service, and to some extent in steam passenger service, the electric control has been adopted. In this type of brake the braking power attains a maximum in five seconds after application, whereas it required fifteen with the most improved type previously in use.

CHAPTER XI

TRAIN RESISTANCE

Introduction. The energy generated and applied by the locomotive is applied to overcoming the resistance to motion of the train. This resistance arises from a number of sources, as will be apparent from the following brief discussion, but in general the total resistance includes that resistance that a train encounters on a straight level track, and that due to curves and gradients. A thorough understanding of the nature and amount of train resistance is essential to the solution of any location problem. Train resistance may be classified as follows:

I. Internal frictional resistance of the locomotive.
II. External resistance.
    1. Atmospheric resistance.
    2. Track resistance.
    3. Journal friction.
    4. Rolling friction.
    5. Inertia resistance.
    5. Grade resistance.
    7. Curve resistance.

The last two of the above items are not included in the term "train resistance" as it is ordinarily defined, the term being commonly understood to include the resistance to the motion of the train on straight level track, hence these forms of resistance will be discussed in other chapters.

Internal Resistance of the Locomotive. While the resistance due to the moving machinery of the locomotive, caused by the inertia and friction of the moving parts, decreases the per cent of the indicated horsepower of the cylinders that is delivered to the drivers, it is not resistance that must be overcome by the tractive effort of the locomotive, that is, by the adhesion of the wheels to the rails. By means of the locomotive testing plants which are now in operation in this country (See Chapter VIII), the internal frictional losses can be accurately determined. The indicator cards taken from the cylinders together with the speed of rotatio ngive the indicated horsepower of the cylinders, while the dynamometer and the equivalent speed of translation give the horspower delivered to the drawbar, and the difference is the amount of internal frictional losses. Results of tests made at the University of Illinois indicate that machine friction varies about directly with the velocity.*

Some of the elements which enter into the internal resistance of the locomotive are the friction in the crosshead, valve gear and cylinders, the friction of the connecting-rod and side-bar bearings and of the driving-wheel journals, and the inertia of the moving parts to some extent. The American Locomotive Company assume the internal friction to be 1.11 per cent of the weight on the drivers. The resistance from cylinders to drivers may be taken from the American Railway Engineering Association formula, as,

$$R=18.7T+80N;$$

R=resistance in pounds, T the weight in tons on the drivers, and N the number of driving axles.

External Resistances. The locating engineer is chiefly concerned with those resistances which tend to reduce the weight of train load that can be pulled over a division by a locomotive, for it is with this resistance that he must reckon in the adjustment of grades and in the choice of alignment. Owing to the variableness of conditions affecting most of the factors entering into train resistance, it is impossible to derive a formula or to formulate a rule for freight tonnage rating between stations that will be universally applicable, yet for the purpose of comparing locations, formulas may be used with sufficient accuracy. In order better to understand the limitations of such formulas, a study of the elements that enter into train resistance may be of value.

Atmospheric Resistance. Atmospheric resistance results primarily from the motion of the train, and comprises the following elements: (1) Resistance on the front end, (2) resistance due to suction at the rear end, (3) atmospheric friction along the sides of the train, and (4) resistance due to a side wind blowing the train so that it crowds one rail thereby increasing the flange friction.

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* Bulletin No. 82, Eng. Exp. Sta., Univ. of Ill.

The resistance on the front end in still air would be equal to the pressure of the wind blowing at the speed of the train against the front end. The pressure of any fluid against a surface is shown in mechanics to vary with the square of the velocity. Experiments at Eiffel Tower and at other places show the pressure in pounds of the wind on a flat surface to be $0.003V^2A$, where V is the velocity of the wind in miles per hour and A is the area exposed in square feet. The pressure due to wind on the convex side of a cylinder is equal to two-thirds the pressure on the projected area, as may be shown by principles of mechanics. The front end of a locomotive is composed chiefly of curved surfaces, consequently the air pressure or resistance may be taken as $0.002V^2A$, V being the velocity of the wind in miles per hour. This is the value adopted by the American Railway Engineering Association and the one used by the American Locomotive Company, and was first proposed by Mr. F. J. Cole as the result of an extended series of observations.* In case the wind is blowing, V may be taken as the velocity of the train relative to the wind, that is, V would be the sum of the velocity of the train and of the wind in the case of their motions being in opposite directions, and their difference, if in the same direction. The pressures of wind on flat surfaces as determined by the U. S. Signal Service at Mt. Washington, N. H., varied from 0.5 lb. at 10 miles per hour velocity to 40.0 lbs. per sq.ft. at 100 miles per hour, 5 to 10 lbs. being the pressure of an ordinary high wind and storm, representing a wind velocity of about 40 to 50 miles per hour.

The area of the front end of a locomotive may be 100 to 150 sq.ft., averaging perhaps 125 sq.ft. This would give as an average resistance

$$R=0.25V^2.$$

While most experiments seem to indicate that the total pressure does not vary directly as the area exposed, the above results have been widely accepted and used.

Resistance due to suction at the rear end caused by the formation of a partial vacuum by the train is probably not more than half the resistance at the head end. No specific information in this connection is available.

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* *Railway Age Gazette*, Oct. 1, 1909.

From certain experiments made at Purdue University,* Dean W. F. M. Goss draws the following conclusions as to the atmospheric resistance to cars:

1. The resistance offered by still air to progress of locomotive and tender running at the head of a train is approximately ten times greater than that which acts upon any intermediate car of the same train.

2. The resistance offered by still air to the progress of the last car of a train is approximately two and a half times that which acts upon an intermediate car of the same train.

Wind having a velocity of less than 10 miles per hour is essentially still air.

Side atmospheric resistance depends upon the length of train and the kind of cars composing it. A train consisting of all box cars or all flat cars has much less resistance than one consisting of flat and box cars alternating. Vestibuling passenger coaches very greatly reduces the resistance due to atmospheric friction. However, the atmospheric resistance on passenger trains is much less than on freight trains generally.

A strong side wind may cause more resistance than a head wind inasmuch as it forces the car trucks against one rail, thereby causing the flanges to grind on the gauge of the rail. The resistance from this source may approximate the total side pressure multiplied by the coefficient of friction of cast iron on steel, or approximately one-fourth of the lateral area times the wind pressure per square foot. Assuming the exposed area of the average car as 400 sq.ft. and the coefficient of kinetic friction as 0.20, the resistance would be as follows, using the values of wind pressure given above:

TABLE XXII

AIR RESISTANCE DUE TO SIDE WIND

Velocity of Wind, M.P.H.	Pressure on Car, Lbs.	Total Resistance, Lbs.	Resistance per Ton, Lbs.
10	120	24	0.4
20	480	96	1.6
30	1080	216	3.6
40	1920	384	6.4
50	3000	600	10.0
60	4320	864	14.4

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* "Locomotive Performance," p. 407.

As will be seen from the values of ordinary train resistance given later in this chapter, the resistance due to a strong side wind may be equal to or greater than the total train resistance due to motion under ordinary conditions.

Track Resistance. When a car is running on straight level track, its trucks oscillate from side to side to a certain extent, striking the flanges first on one side and than on the other, at each impact dampening the velocity of the train somewhat. The condition of the track and the weight of the rolling stock have much to do with the amount of resistance from this source, the lighter cars, such as interurban passenger cars and freight cars being particularly subject to this action. The concussions of the wheels against the gauge of the rails cause an increase in flange friction besides directly by impact impeding the velocity of the train.

Lack of rigidity in track is the second factor entering into track resistance. Low joints, light rails, poor ballast, and poor maintenance tend to increase the resistance from this source. The introduction of stiff heavy rails has done as much as any other one thing perhaps to decrease this resistance. A large radius in the throat of the flange and a small radius of curvature on the head of the rail also tend to decrease track resistance by diminishing flange friction. The Master Car Builders' standard flange together with the tread of the A. S. C. E. rail section give good results in lessening flange friction and in absorbing shocks from lateral concussions.

Track resistance varies probably somewhat more rapidly than the first power of the speed but not so rapidly as the square of the velocity, although it is commonly considered to vary as the square of the velocity. The resistance due to the series of impacts would vary as the square of the velocity, but that resulting from flange friction, low joints and similar factors would vary more nearly as the first power.

Wheel Resistance. Wheel resistance comprises journal friction and rolling friction. *Journal friction* has been studied extensively under various conditions of lubrication, etc. The friction of lubricated surfaces is governed by laws entirely different from those relating to static and dry friction, and depends almost entirely upon the lubricant. The coefficient is not constant but varies with the temperature, velocity and pressure. At ordinary temperatures, the coefficient decreases slightly with the temperature, while for higher temperatures, such as might occur in a hot box, the coefficient increases rapidly. At the higher temperatures, the lubricant becomes so fluid that it is squeezed out of the bearings, allowing the metal parts to come in contact with each other to a greater or less extent, while at the lower temperatures the viscosity of oils is increased. The exact temperatures at which these marked changes occur vary with the different lubricants.

The coefficient of starting friction is much higher than during motion owing to the fact that the lubricant is squeezed out of the bearings while standing, and at starting the friction is similar to that of dry bearings. As speed picks up, the bearings become lubricated, the oil is warmed, and, as a consequence, the friction falls off. The coefficient of starting friction averages about five times as great as at 150 ft. per minute rubbing velocity, although at times it was much higher.

The force required to pull a wheel forward against journal friction will be

$$P=\frac{f \cdot Wr}{R},$$

where f is the coefficient of friction, W the weight on the wheel, r and R, the radius of the axle and wheel respectively. With a 4-in. axle and 32-in. wheel and assuming f as 0.005, the resistance per ton is 1.25 lbs.

From the foregoing, it may be deduced (1) that at temperatures below freezing or near freezing, journal friction may be much greater than at normal temperatures and that hot boxes, on the other hand, may very greatly increase journal friction; (2) the resistance at starting may amount to 10 or 20 lbs. per ton due to journal friction alone, but that it rapidly falls off as speed is attained owing to better lubrication and the warming of the journals. Tests on the C., R. I. & P. Ry. with trains of 35 to 45 cars showed starting friction as 10 to 18 lbs. per ton, the mean being 14.1 lbs. The same tests showed a starting resistance of 30 lbs. per ton when the train stood overnight and 6 lbs. per ton when the stop was practically instantaneous. Owing to the decrease in the coefficient of friction for higher pressures, the resistance due to journal friction is less per ton for loaded cars than for empties. It has been observed also that the friction at any speed is less if the speed has been reduced to that velocity than if it has been increased to it.

Rolling Friction. When a roller such as a car wheel rolls on a plane, the face of the wheel as well as the surface of the plane is deformed slightly, and a portion of the work done in this deformation is lost owing to the motion of the wheel forward. As it is, the wheel must be continually lifting itself up a miniature crest in front of it, or what amounts to the same thing, exerting enough force to compress the wheel and the track. The total reaction stands at an angle and applied to the wheel at a distance a from the vertical passing through the center. Taking moments gives the relation $P=\frac{Wa}{R}$. For railroad wheels, the value of a has been found to be about 0.02 in. Using this value, P becomes 1.5 lbs. per ton for a 32-in. wheel. This force is probably independent of the velocity as might be expected from the principles of mechanics.

Resistance Due to Inertia. One of the laws of mechanics is that when an unbalanced force acts upon a body, it produces an acceleration in the direction of the force that is proportional to the magnitude of the force and inversely proportional to the mass of the body. That is, if a body containing W pounds of mass is acted upon by a force of F pounds, the acceleration is given by the equation,

$$a=\frac{CF}{W}, \quad \text{or} \quad F=\frac{1}{C}Wa,$$

a being the acceleration in feet per second. The coefficient C is found by experiment to have a value under normal conditions of 32.16. Hence, having given the weight of the body and the acceleration desired, the force required to produce this acceleration in a distance s feet is capable of calculation.

From the foregoing,

$$F=\frac{Wa}{32.16}.$$

Multiplying by ds

$$Fds=\frac{Wa}{32.16}ds=\frac{W}{32.16}\frac{dv}{dt}ds$$
$$=\frac{W}{32.16}\frac{ds}{dt}dv=\frac{W}{32.16}vdv.$$

Integrating between the limits v_1 and v_2,

$$Fs=\frac{1}{2}\frac{W}{32.16}(v_2^2-v_1^2)$$

v_1 and v_2 being two different velocities in feet per second. Computing for $W=2000$ lbs. or 1 ton and changing feet per second to miles per hour,

$$F_1=\frac{67.0}{s}(V_2^2-V_1^2). \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The force F_1, however, is simply the force which is required to produce the change in velocity in translation in one ton neglecting frictional resistances. The wheels must not only be accelerated in translation, but they must be given an angular or rotational acceleration as well. By an extension of the above formulas for translation to apply to a body in rotation, it is found that the moment required to produce an angular acceleration, α radians per second per second in a car wheel is $I\alpha$, I being the moment of inertia of the car wheel about its axis of rotation in gee-pound feet squared. This moment is equal to Pr, P being the force applied at the circumference necessary to accelerate the wheel and r, the radius of the wheel, about 16 ins. $I=\frac{wk^2}{32.16}$, where k is the radius of gyration of the car wheel, equal for the average wheel to about 12 ins. The mass, w, of a car wheel is as follows:

600 lbs. for 60,000 lbs. capacity car.
650 " 70,000 " " "
700 " 100,000 " " "
700 " passenger coach.
730 " tender trucks.

The total force required to change the velocity in feet per second from v_1 to v_2 equals

$$\frac{W}{64.32s}(v_2^2-v_1^2)+\frac{wk^2}{64.32s}(\omega_2^2-\omega_1^2)$$
$$=\frac{W}{64.32s}(v_2^2-v_1^2)+\frac{wk^2}{64.32r^2s}(v_2^2-v_1^2)$$
$$=\left(\frac{W}{64.32s}+\frac{wk^2}{64.32r^2s}\right)(v_2^2-v_1^2).$$

ω_1 and ω_2 being the angular velocities of rotation.

The second term of the first quantity amounts to about 8 per cent of the first for unloaded cars and about $2\frac{1}{2}$ per cent for loaded cars. For a car having a weight T tons and the above dimensions for the wheels, the force required to change the velocity from V_1 to V_2 miles per hour would be found as follows:

$$F=\left(\frac{2000T}{64.32s}+\frac{700}{64.32}\times\frac{1}{1.33^2s}\right)(v_2{}^2-v_1{}^2).$$

Reducing velocities to miles per hour by multiplying by $\left(\frac{5280}{3600}\right)^2$,

$$F=\left(\frac{67.0T}{s}+\frac{13.6n}{s}\right)(V_2{}^2-V_1{}^2)\quad.\quad.\quad.\quad.\quad.\quad(2)$$

where n = the number of wheels;

T = the weight of the train in tons;

s = distance in feet in which the velocity changes from V_1 to V_2 M.P.H.

For a 100,000-lb. capacity car weighing empty 37,100 lbs. the second part of this expression representing the kinetic energy of the wheels, is 2.3 per cent of the first when the car is loaded and 8.5 per cent when empty. The late A. M. Wellington used 6 per cent as an average increase in the drawbar pull required to accelerate the wheels in rotation. (This quantity also represents the kinetic energy stored in the wheels due to rotation, a matter that will be discussed at another place.) Owing, however, to the increase in the live load in proportion to the dead weight of cars since the introduction of larger cars and the greater care exercised to secure more completely loaded cars, perhaps $4\frac{1}{2}$ or 5 per cent would more nearly represent average conditions. Using 5 per cent, therefore, as an average figure, the force required per ton to accelerate a train is from (1),

$$F=\frac{67.0}{s}(V_2{}^2-V_1{}^2)\times1.05=\frac{70.4}{s}(V_2{}^2-V_1{}^2).\quad.\quad.\quad(3)$$

As an illustration, find the force required to accelerate a train of 10,000 tons up to 20 M.P.H. in going one-half mile, starting from rest.

$$F=\frac{70.4}{2640}\times20^2\times1000=10,700\text{ lbs.}$$

$\frac{Mi}{hr}\times\frac{3600}{5280}$

The need of a large drawbar pull at low speeds to produce rapid acceleration, such as in passenger service, is at once apparent.

Formulas for Freight Train Resistance. From the foregoing discussion, it is obvious that many factors enter into train resistance, some of which are independent of the velocity, some vary inversely as the velocity, some directly as the first power and some as the second power of the velocity. Certain resistances are independent of the weight while most of them vary with the weight. With this in mind, a general formula for train resistance would take on this form, omitting resistances due to grade, curvature and inertia:

$$R_t=\left(C+\frac{A}{V+B}+HV+KV^2\right)W+DV^2.$$

Where R_t is the total resistance;
V, the velocity;
W, the total weight;
C, a constant;
H, K, and D, experimental coefficients;
A and B, constants introduced to make the equation of general form.

Various experiments have been made to determine train resistance, but train resistance depends upon such a variety of conditions, such as the weight of cars, shape of cars, character and condition of trucks, character and condition of track, etc., that a general formula that will be accurate and reliable is difficult, if not impossible, of attainment. Most of the formulas that have been proposed have abandoned the theoretical general form indicated above, and have been made entirely empirical.

From tests made on the Baltimore and Ohio Railroad and on other roads, the following formula for train resistance was derived,*

$$R_t=2.2T+122C,$$

R_t being the total resistance in pounds, T the weight of the train in tons, and C the number of cars in the train.

This formula has been adopted by the American Railway Association and is very widely used. When corrected for temperature and other local conditions, it gives very satisfactory results. However, it does not provide for the influence of different speeds, the tests as made indicating that the resistance was unaffected by the speed between 7 and 35 miles per hour.

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* Proc. Am. Ry. Eng. Assn., Vol. II, p. 647.

Professor E. C. Schmidt, from an extended series of observations on freight train resistance * that had been made under the direction of the Experiment Station of the University of Illinois, derived the following formulas which take into account the average weight of the cars as well as the speed of the train. The equations show train resistance per ton and are for speeds of 40 M.P.H. and less.

Average weight of car	15 tons;	$R=7.15+0.085V+0.00175V^2$
	20 "	$R=6.30+0.087V+0.00126V^2$
	25 "	$R=5.60+0.077V+0.00116V^2$
	30 "	$R=5.02+0.066V+0.00116V^2$
	35 "	$R=4.49+0.060V+0.00108V^2$
	40 "	$R=4.15+0.041V+0.00134V^2$
	45 "	$R=3.82+0.031V+0.00140V^2$
	50 "	$R=3.56+0.024V+0.00140V^2$
	55 "	$R=3.38+0.016V+0.00142V^2$
	60 "	$R=3.19+0.016V+0.00132V^2$
	65 "	$R=3.06+0.014V+0.00130V^2$
	70 "	$R=2.92+0.021V+0.00111V^2$
	75 "	$R=2.87+0.019V+0.00113V^2$

Fig. 22 shows these formulas graphically and Fig. 23 shows typical plots of the data from which they were derived. Fig. 24 is a portion of the chart from a dynamometer car test for train resistance, the dynamometer car being attached between the tender and the train.

Other formulas for train resistance which have been much used are the *Engineering News* formula, $R=2+\frac{V}{4}$, and the Baldwin Locomotive Works formula, $R=3+\frac{V}{6}$. Neither of these has any rational or extended experimental basis and they do not represent the more scientific period of train operation of recent years. Mr. S. L. Ciuett derived the following formulas from curves devised by Mr. Wellington: For empty cars,

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* Bulletin 43, Eng. Exp. Sta. Univ. of Ill.

$$R=5.4+0.001V^2+\frac{70}{(V+3)^2},$$

and for loaded trains,

$$R=3.8+0.0076V^2+\frac{16.4}{(V+1)^2}.$$

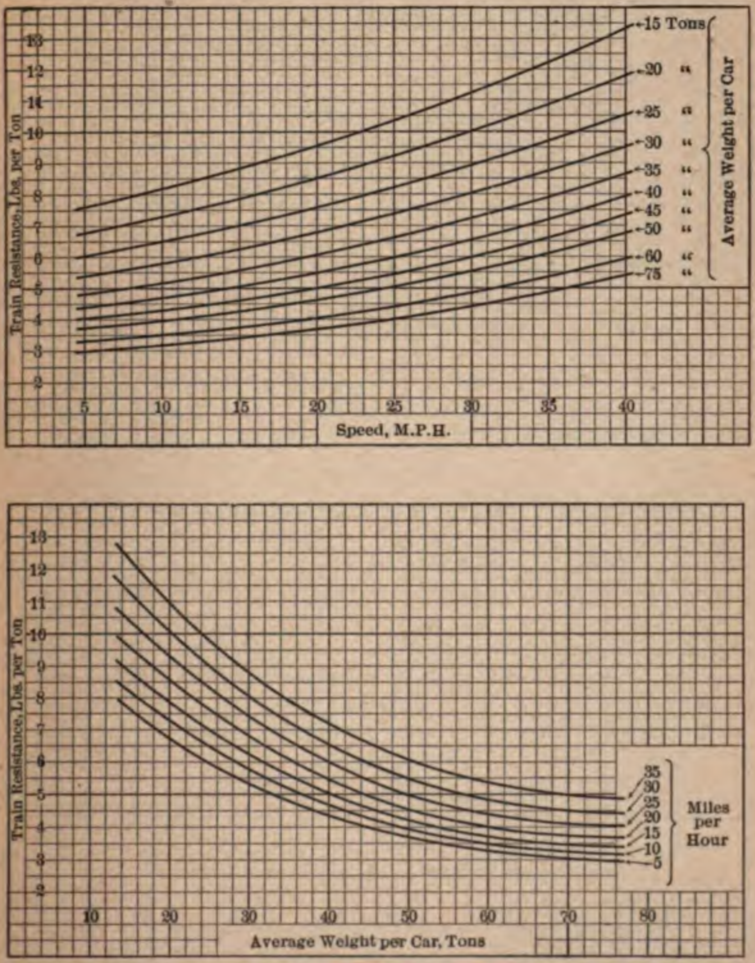

FIG. 22.—Train Resistance Curves.

Both of these give results that are too high for modern rolling stock.

Freight train resistance is less for trains made up of cars of uniform type than for trains of alternating types. That is, resistance is less for all box cars or all flat cars than it is for mixed box cars and flat cars alternating.

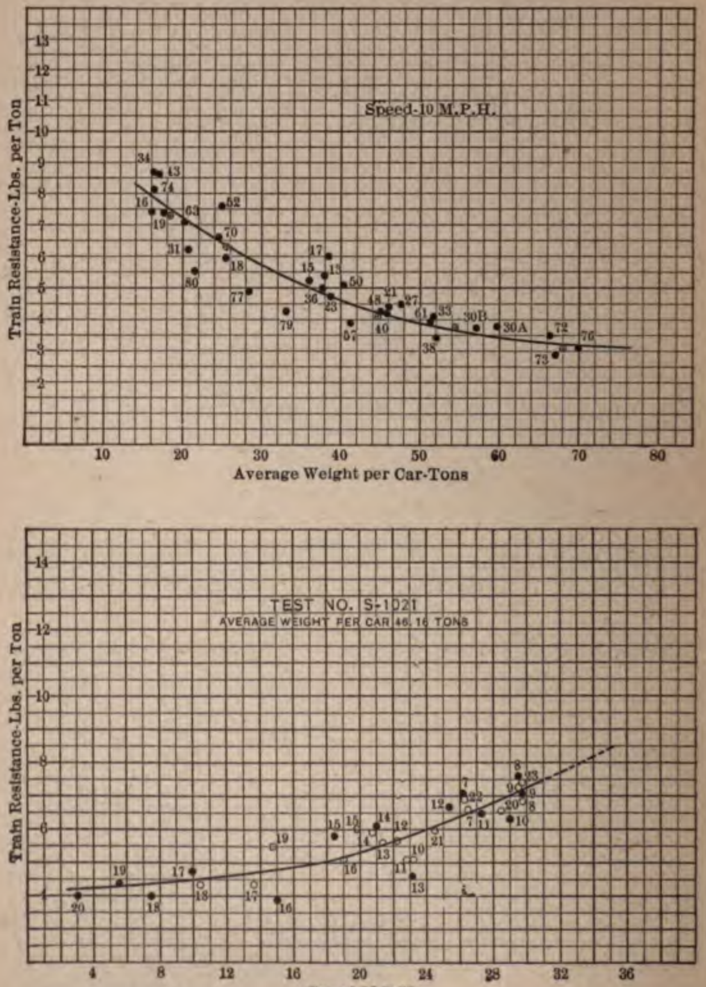

FIG. 23.—Results of Tests of Train Resistance.

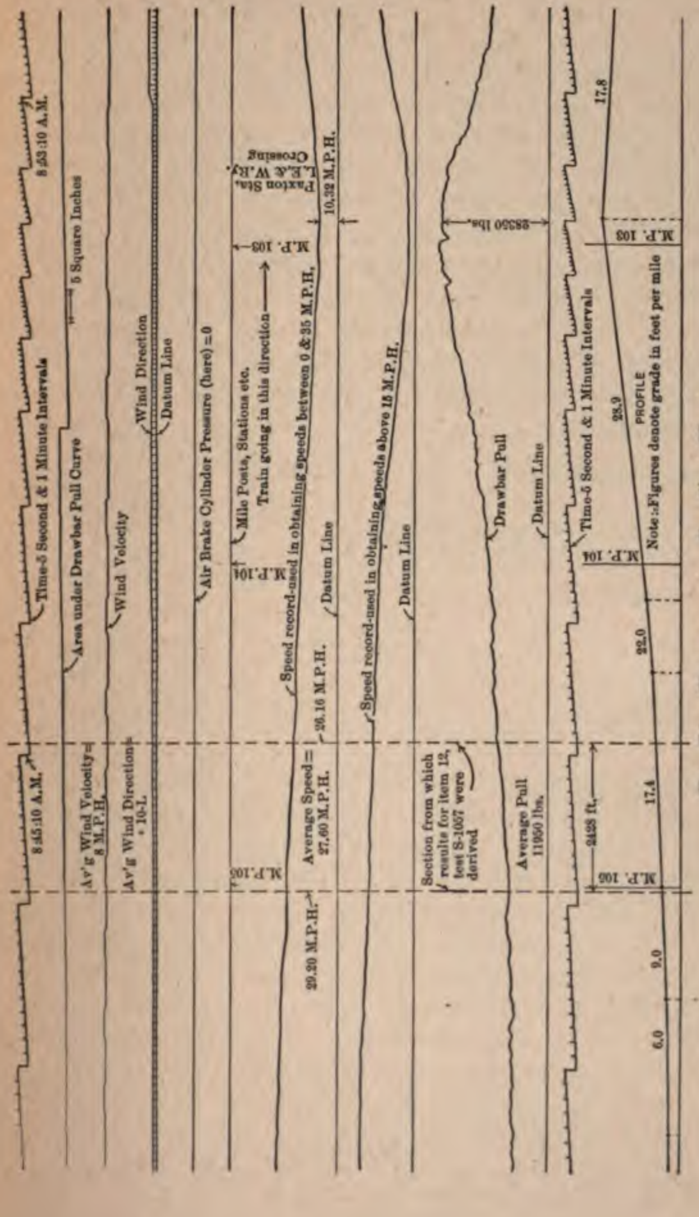

FIG. 24.—Dynamometer Car Test Chart.

Passenger Train Resistance. Vestibuling passenger cars and the absence of side doors tend to reduce the resistance of passenger trains, while, on the other hand, the high speeds tend to increase it above that of freight trains. The small proportion of the live load to the dead weight of cars and the greater uniformity of cars in respect to height and general construction make the resistance of passenger trains more definite than that of freight trains. Notwithstanding this fact, however, very few careful experiments have been made to determine passenger-train resistance. This condition obtains, doubtless, chiefly due to the fact that resistance of passenger trains is not so vital a matter in the operation of such trains as is freight train resistance in the make-up of freight trains.

The following formulas for passenger train resistance have been widely used:

American Locomotive Co. $R=5.4+0.002((V-15)^2+\frac{100}{(V+2)^3}$;

Baldwin Locomotive Co., $R=3+\frac{V}{6}$;

C., B. & Q. R. R., $R=2.5+\frac{V^2}{468}$;

Penna. R. R., $R=3+0.1315V$;

General Electric Co., $R=\frac{50}{\sqrt{T}}+0.03V+\frac{0.002V^2}{T}A\left(1+\frac{N-1}{10}\right)$;

R being the resistance in pounds per ton, V the velocity in miles per hour, A the area of end of train in square feet, T the total weight in tons, and N the number of cars.

It will be noted that in all of these formulas, the resistance increases with the speed above ten miles per hour and in most of them it is considered as increasing with some power of the speed higher than the first power.

The train resistance of the type of car commonly used on electric railroads makes it necessary to consider such resistance apart from that of steam train resistance. The General Electric Company, after an extended series of tests, devised the formula given above for the resistance of trains of this class. The first member of the quantity is supposed to give the resistance due to journal friction and is limited to a value of 3.5 lbs.; the second term gives the rolling friction, assumed proportional to the speed; and the third term, the resistance due to the atmosphere and the track, assumed to vary as the square of the speed.

Effect of Temperature and Adverse Operating Conditions. Allowance must be made for cold weather, because of the lessened efficiency of the locomotive due to increased radiation and bad rail and also because of greater train resistance. From observations made on the Baltimore and Ohio R. R., the following modifications of the standard formula for train resistance to provide for variations due to the influence of cold weather conditions were adopted by the American Railway Engineering Association:

Temperature over 35° Fahr. . . . . . . $R_t = 2.2T + 122C$
Between 20° and 35° Fahr. . . . . $R_t = 3.0T + 137C$
Between 0° and 20° Fahr. . . . . $R_t = 4.0T + 153C$
Below 0° Fahr. . . . . $R_t = 5.4T + 171C$

Professor E. C. Schmidt has tabulated the practice of a number of railroads in making allowance for cold weather conditions as given in Table XXIII.

TABLE XXIII

REDUCTION OF TONNAGE RATING DUE TO COLD WEATHER

Railroad.	TEMPERATURE, DEGREES FAHR.				
	45+	32–45	20–32	0–20	–0
		Per cent	Per cent	Per cent	Per cent
C. G. W.	normal	8	16	16	25
C. & E. I.	"	10	20	30	35
C. & O.	"	5	10	20–25	30
Penna.	"	5	10	15–30	30
N. Pac.	"	10	10	20	35
C. of N. J.	"	10	10	20	
Erie.	"	normal	5	15	20
C., B. & Q.	"	"	10	15	20
C., M. & St. P. .	"	"	5	10	20–30
D. & R. G.	"	"	15	15	25
L. V.	"	"	5	15	25
D. & I. R.	"	"	10	10	20–25
C. & N. W.	"	"	normal	10–25	
Can. Pac.	"	"	"	. . . .	8–25
B. & M.	"	"	"	7–15	12–22
G. T.	"	"	"	normal	5–20

Train Loading. A few years ago railroad operators aimed at the maximum train load possible, but at the present time there is a tendency toward a more moderate weight of train load and a more rapid movement, especially for certain classes of freight. The make-up of trains will be discussed at another place, but it should be pointed out in this connection that the study that has been made of train resistance has made possible a more scientific and exact method of making up trains to operate reliably and to the best advantage over any given division. Table XXIV shows the results obtained by a number of railroads, which indicate that under conditions of careful operation railroads rate their trains within two or three per cent of the theoretical power of the locomotive.

TABLE XXIV

COMPARISON OF ACTUAL WITH THEORETICAL TRAIN LOADS

Railroad.	Speed, M.P.H.	Tons behind Tender.	Tractive Power Available.	RESISTANCES.			MARGIN OF POWER.	
				Locom.	Cars.	Total.	Lbs.	P.ct.
Penna., frt......	17	5973	45,300	3401	41,671	45,072	228	0.5
Virginia, frt.....	....	6856	50,350	3495	46,855	50,350	0	0.0
Virginia, frt.....	....	6000	50,350	3496	42,000	45,496	4854	9.7
Penna., pass....	69	360	7,660	3573	4,050	7,623	37	0.5
N. Y. C., pass..	70	315	8,322	4551	3,617	8,168	154	1.9
N. Y. C., pass..	60	564	9,870	3949	5,335	9,284	568	6.0

CHAPTER XII

TRAIN OPERATION

Classification of Freight with Respect to Mode of Handling. Freight is classified according to the method of handling into car-load (C. L.) and less-than-car-load (L. C. L.). The latter is sometimes called platform, way, parcel, or peddler freight, owing to the fact that it is handled from the station platform to a considerable extent. It consists of separate articles that are billed to the consignee individually. Car-load freight consists of any commodity that is shipped in essentially car-load lots, such as coal, grain, live stock, oil, ore, structural steel, cement, etc. Car-load freight is handled from freight houses to some extent, but chiefly from special industry tracks, industry roads, and sidings.

With regard to the character of service, freight is classified as

Quick dispatch (Q. D.) freight;
Time freight;
Slow freight;
Local freight.

Quick dispatch freight, variously termed symbol, manifest, red letter, cannon ball, or otherwise, consists of the fast freight and usually includes perishable commodities, such as fruit, fish, fresh meat, etc., live stock, and high-class merchandise. It is hauled by special service trains which are so loaded as to allow fast running time. These trains operate according to a definite time schedule and with a view to regularity as well as fast time. Special arrangements are frequently necessary for caring for quick dispatch freight, such as icing cars in the case of fruit and fresh meats, watering live stock, etc. All L. C. L. freight is commonly classed as quick dispatch.

Time freight requires regularity of movement rather than great rapidity, in order that shippers may depend upon the *time* of transportation from the point of origin to the point of destination. This is accomplished by giving trains carrying such commodities a time schedule but loading them about the same as for slow freight. Time freight consists of such commodities as machinery, canned goods, flour, oil in tanks, sugar, salt, furniture, and stoves in car-load lots, structural steel, pianos, organs, etc.

Slow freight consists chiefly of raw materials, such as coal, ore, broken stone, pig iron, sand, lumber, etc., being materials that do not represent any particular articles or orders, one car of the material of a given grade answering the needs of the consignee as well as another. This class of freight is most commonly handled from special tracks.

Local freight consists of that which originates on the line, destined for some point on the same line, or making its first movement from the point of origin to the first terminal en route, or the movement from the last terminal to its final destination. It is moved on regular schedule trains that stop at all points where freight is expected to be received or delivered.

The relative cost of handling these different classes of freight is not accurately known, as railroads have not kept records sufficiently complete to permit such costs to be computed.

Making Up Trains. Trains are designated as regular if they are assigned times of movement on the time-tables, and extra, if they are not so assigned a moving time but move entirely according to the dispatcher's orders. Regular trains may consist of two or more sections, but they are represented as one train in the time-table. Likewise, an extra train may comprise several sections running on the same train order. Trains are made up according to the conditions of track, grade, alignment, etc., under which they are to operate. Frequently they are made up in the yard for only the succeeding division, but where practicable, if the following divisions are similar as to operating conditions, it is desirable to make up trains so that they may proceed as far as possible without alteration.

The destination of any particular car is controlled necessarily by its contents and it is impracticable to secure a complete trainload destined for any particular point. For this reason, it is necessary to break up trains at junction points and to distribute separate cuts of cars at various points along the line. Trains doing this kind of business are usually made up by arranging the cars in station order beginning at the locomotive so that the cars may be most conveniently set out while the L.C.L freight is handled from the rear of the train. Trains usually have the loaded cars at the front and empties at the rear in order to prevent breaking in two while passing over "choppy" gradients. The effect of this make-up policy should be kept in mind by the locating engineer in the choice of ruling gradients and in determining the length of line over which any gradient is adopted as the ruling gradient, and in adapting the location generally to the character of traffic to be cared for.

Locomotive Rating. The proper rating of locomotives in terms of the load to be handled while making up trains will have much to do with successful operation. Engines are loaded at terminals with a view to one or more of three distinct objectives or desiderata:

1. To move the maximum tonnage per engine consistent with making the run in a specified time between terminals, taking into account the ordinary delays.

2. To move the maximum tonnage per day per engine for a given length of time, including in this period all the time of the engine whether in active operation or in undergoing repairs.

3. To move traffic at a minimum cost per ton-mile.

Which of these will govern will depend upon the class of freight handled. The first would obviously apply chiefly to quick dispatch and time freight and the third to slow freight primarily, while the second would apply in a measure to all classes.

The tonnage that an engine can pull depends first upon the power and condition of the locomotive and second upon operating conditions, including:

1. Rate of ruling grade.
2. Length of maximum grades.
3. Average grade.
4. Sharpness of curves.
5. Length of curves.
6. Total curvature.
7. Density of traffic.
8. Character of traffic.
9. Running time allowed.
10. Percentage of dead weight to live load.
11. Average weight of cars.

12. Condition of rolling stock, journals, drawheads, etc.
13. Passing track facilities.
14. Condition of track.
15. Weather conditions, precipitation and temperature.
16. Wind velocity and direction.
17. Skill of trainmen.
18. Signaling and communication facilities.
19. Number of tracks.
20. Length of divisions.

The desired rating is naturally the economic rating, that is, the one which will allow the locomotive to earn the maximum net returns for the railroad company, and obviously this depends upon the class of freight hauled, since the different classes have different tariff rates. For any given class of freight, the economic rating will in general be that which permits the greatest tonnage per engine-mile. Mr. John A. Droege* estimates that if the rating be made about 80 per cent of the maximum possible with the given drawbar pull, the most economic operation results. He gives an example of one division dropping the rating from 100 to 80 per cent of the available drawbar pull, by which means the coal consumed per ton-mile was decreased 9.3 per cent.

Formerly locomotives were rated in terms of the number of loaded cars that they could pull over a division, two empties being usually considered as equivalent to one loaded car. The number that the locomotive could pull was determined by actual tests, which were frequently made under operating conditions different from those obtaining at the time of normal operation. Recent investigations in train resistance, however, make it possible to rate locomotives with a reasonable degree of accuracy on a tonnage basis, results attained usually being within about 5 per cent of that which was intended. Locomotives are usually rated in terms of tons of train load or in terms of "M's," an "M" signifying 1000 pounds of train load that the locomotive can pull over the division for which the rating is intended to apply. Thus a train of 2790.3 M's means a train having a gross tonnage of 2,790,300 pounds, or 1395 tons. Since loaded cars are weighed on track scales and the weights of empties are stenciled on their sides, the total weight of the train can be readily determined. Tonnage computers are used in some yards which add up the tonnage adjusted to grades and other operating conditions instead of the actual tonnage. The tonnage over any division for a given engine must be reduced when operating conditions are unfavorable on account of bad weather or poor track. (See Chapter XI.) Fig. 25 shows a tonnage rating diagram* for a heavy consolidation locomotive and illustrates a method of making up such a diagram. It gives the uniform velocity at which the locomotive will pull any given tonnage up a given grade, or over a given grade system. These curves are the graphs of the following formulas after deducting the weight of the engine and tender from the total weight of train:

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* "Freight Terminals and Trains," . 156.

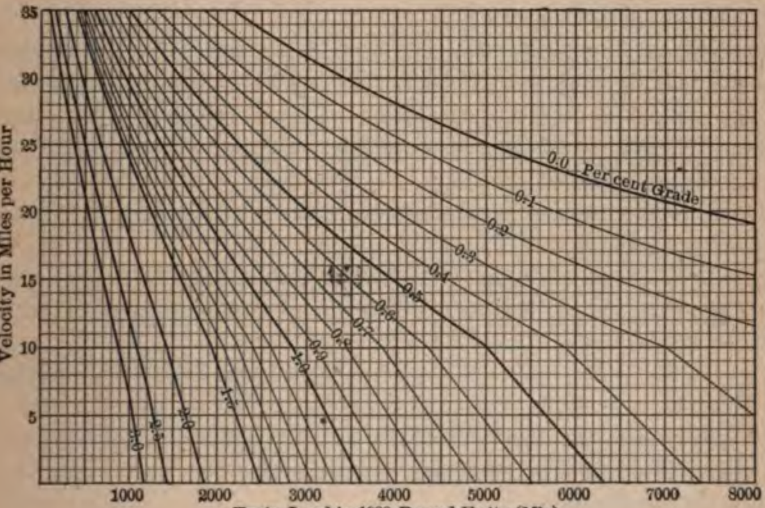

FIG. 25.—Train-rating Diagram.

$$W = d^2B\frac{L}{D}\left(\frac{10{,}450 - 392V\frac{L}{D}}{24.75 + 110G}\right)$$

for velocities between 0 and 10 M.P.H.;

$$W = d^2B\frac{L}{D}\left(\frac{10{,}450 - 392V\frac{L}{D}}{1.65V + 8.25 + 110G}\right)$$

for velocities between 10 and 35 M.P.H.

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* Proc. Am. Ry. Eng. Assn., Vol. XI, p. 1324.

d being the diameter of the locomotive cylinders in inches, *D* the diameter of the drivers in inches, *L* the length of stroke in inches, *B* the boiler pressure, *V* the velocity, *G* the per cent of grade and *W* the weight of train including the engine in pounds. These formulas follow from taking the tractive effort as

$$d^2B\frac{L}{D}\left(\frac{10{,}450-392V\frac{L}{D}}{11{,}000}\right).$$

and the resistance as 4.5 and $1.5+0.3V$ pounds per ton respectively for the two cases.

7 **Economic Speed.** In the adjustment of grades, the engineer should take into account the speed at which the trains are to be operated and the effect of grades upon the economic speed. The chief factors entering into the determination of the economic speed are:

1. The tractive effort decreases with the speed, as shown in Fig. 11 and Table XIX.
2. Power is more expensive at the higher speeds.
3. The higher the speed, the greater the number of trips that can be made by one engine.

In the proceedings of the Am. Ry. Eng. Assn., Vol. XI, p. 1328, Messrs. J. D. Isaacs and E. E. Adams presented a valuable discussion on the "Economic and Efficient Speed of Trains," which illustrates a method of studying the question. Two objects are sought:

1. To find the speed that will carry the maximum tonnage over the line in a given time.
2. To find the speed that will permit a given tonnage to be hauled at a minimum cost.

The following paragraphs are extracted from that discussion.

These two propositions are obvious:

1. If engines are rated at the speed that will give the maximum ton-miles per hour per train, this speed will give the maximum tonnage over the line for a given number of trains.

2. Since the cost of operation increases rapidly with the train-mileage, for a given tonnage, the rating which will incur the least train-mileage will be the most economical. In other words, the rating that will give the maximum ton-miles per hour per locomotive will give the maximum tonnage over the

line for a given number of trains, and the tonnage will be hauled at a minimum cost.

The problem is, therefore, to determine the speed on the given average grade that will enable the locomotive to accomplish the maximum ton-miles per hour. The average grade of a line is obtained by dividing the sum of all adverse ascents by the length of the line in 100-ft. stations.

The following formula gives the net tonnage that can be pulled by the consolidation locomotive considered at velocities between 10 and 35 miles per hour.

$$T=\frac{(266{,}200-5256V)}{1.65V+8.25+110G}-170,$$

in which, T is the tons pulled exclusive of the engine and tender, V is the velocity in miles per hour, and G is the average grade. Column 2 of Table XXV was calculated from this formula for

TABLE XXV

CALCULATION OF ECONOMIC SPEED

(1) Speed between Stations. M.P.H.	(2) Weight of Train in 2000-lb. Tons.	(3)[1] Number of Trains Each Way per Day.	(4) Loss per Train per Hour for Meets.	(5) Percentage of Running Time.	(6) Ton-miles per Train per Hour (with Meets).	(7) Schedule Speed. M.P.H.	(8) Ton-miles per Hour (no Meets).
10.0	1415	7.07	0.147	0.853	12,060	8.53	14,150
11.0	1355	7.33	0.154	0.846	12,600	......	14,905
12.0	1300	7.68	0.160	0.840	13,100	......	15,600
13.0	1245	8.03	0.167	0.833	13,500	......	16,185
14.0	1190	8.39	0.175	0.825	13,750	......	16,660
15.0	1140	8.76	0.183	0.817	13,870	......	17,100
16.0	1089	9.20	0.192	0.808	14,080	......	17,440
16.9	1044	9.58	0.200	0.800	14,119	13.52	
17.0	1038	9.62	0.201	0.799	14,118	......	17,820
18.0	990	10.10	0.210	0.790	14,100	......	17,880
19.0	941	10.62	0.222	0.778	13,910	......	17,680
19.6	914	......	......	......	......	......	17,914
20.0	895	11.18	0.233	0.767	13,740	......	17,900
25.0	675	14.82	0.309	0.691	11,650	......	16,875
30.0	480	20.80	0.433	0.567	8,150	......	14,440

[1] This is merely the accurate mathematical result. Of course, fractional trains in practice would be provided for by extras, or by using the next even number of trains.

a 1.0 per cent grade. The traffic was assumed as 10,000 tons each way per day, and column 3 was calculated by dividing 10,000 by the corresponding number in column 2. Column 4 was obtained by assuming one-half hour lost at each meet, and the other calculations are apparent. These results are shown graphically in Fig. 26 (*a*); (*b*) gives similar results for various grades with a line drawn joining the points of maximum efficiency; (*c*) represents the conditions for a double-track line, that is, where no stops for meets were considered; (*d*) is a comparison of maximum efficiencies for various conditions of operation.

In the majority of cases considered, Messrs. Isaacs and Adams state, it will be found that if a locomotive is rated for the most economical speed for the average grade, this rating will have to be reduced in order that the train may make a minimum speed of ten miles per hour on the steepest grade. For a line, however, on which the ruling gradient and the average grade are nearly the same, considerable economy can be secured by rating the engine for the most efficient speed.

An instructive series of records * of operation, illustrating economic speed, was kept on the Indiana Division of the Baltimore and Ohio Railway during the months of January and February, 1904. These records applied to the following classes of service:

1. Common freights scheduled to travel about 9 M.P.H., the rating being assumed at the capacity of the locomotive at that speed.

2. Semi-quick dispatch freights, operating at an average speed of 15 M.P.H., the rating of the locomotives being assumed at 72 per cent of that for common freights.

3. Quick dispatch freights, operating at an average speed of 19 M.P.H., the rating being assumed at 60 per cent of that for common freights.

The data collected for each of these classes of trains for separate trips were as follows:

1. Temperature.
2. Number of engines.
3. Number of cars.
4. Traffic carried in ton-miles.

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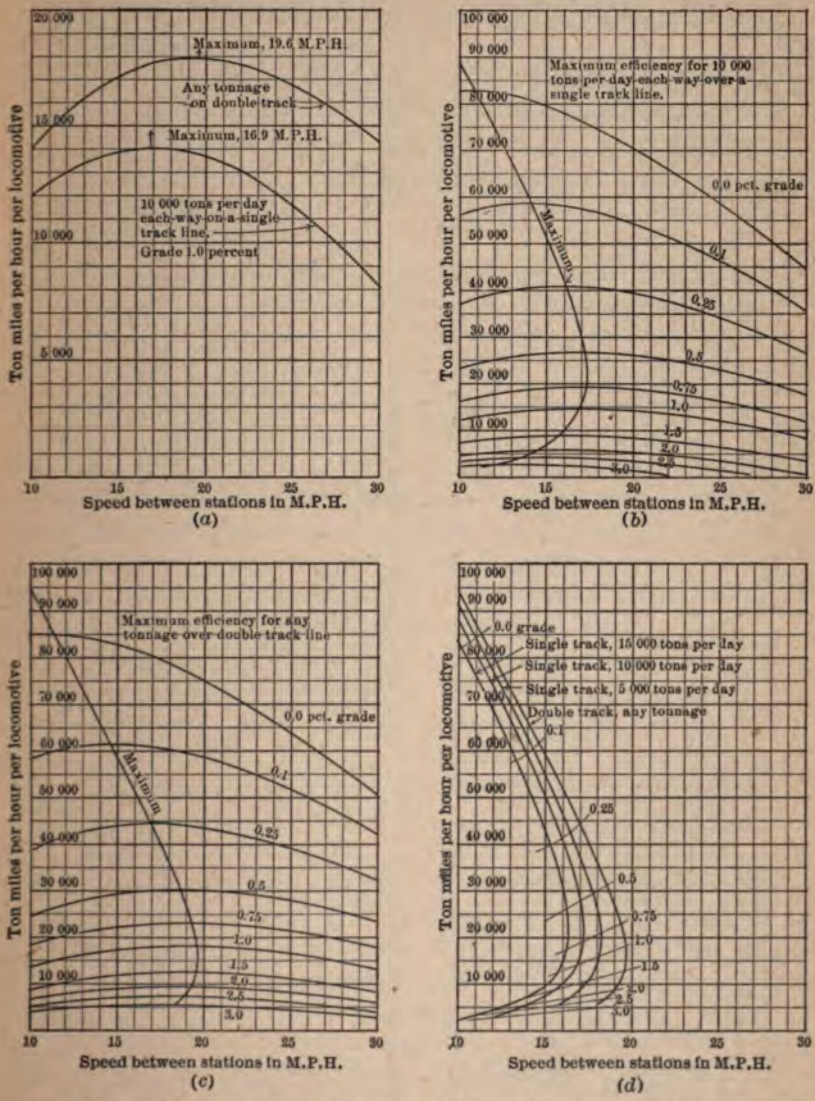
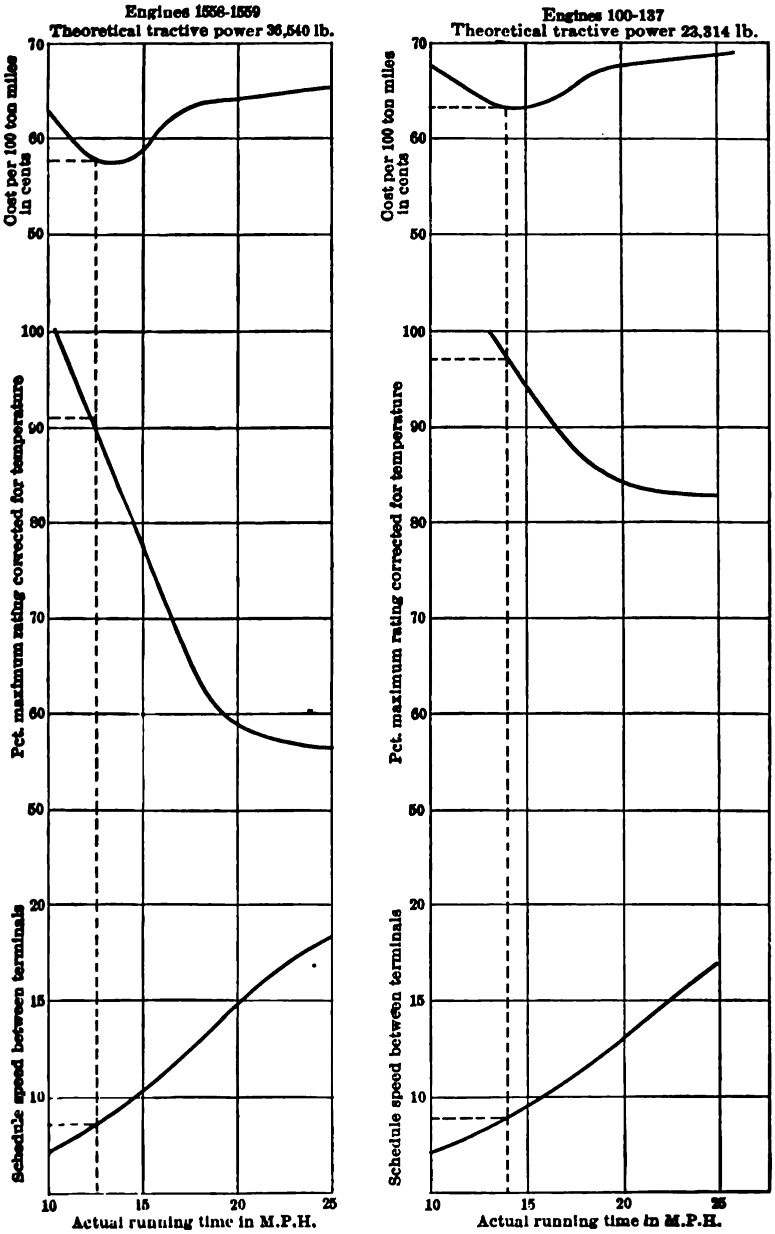
* W. B. Poland, Proc. Am. Ry. Eng. Assn., Vol. IX, p. 795.



(a) (b) (c) (d)

FIG. 26.—Economical Speed for Consolidation Locomotive Weighing 187,000 Pounds on the Drivers.



Engines 1556-1559
Theoretical tractive power 36,540 lb.

Engines 100-137
Theoretical tractive power 23,314 lb.

FIG. 27.—Diagrams Showing Economic Speed.

5. Running time between terminals.
6. Rate per hour for running time between terminals.
7. Total time between terminals.
8. Rate per hour for total time between terminals.
9. Cost of operation, including wages, fuel, repairs, etc.
10. Cost of fixed charges. (Engines valued at $9000 and $11,000, cars $800, interest 5 per cent, depreciation, 5 per cent.)
11. Total cost.
12. Cost per 1000 ton-miles.
13. Per cent hauled of maximum rating for common freight.

The results of these observations are shown in Fig. 27. These diagrams show the comparative cost of fast and slow freight service and to a certain extent the relative economy of heavy motive power. For the heavier engines, the minimum cost is found at a speed of 13 M.P.H., which requires a rating of 88 per cent of the maximum (second diagram), but a speed of 12.5 M.P.H. does not increase the cost of handling appreciably and allows the rating to be 91 per cent of the maximum. From the third chart, it is seen that an actual running speed of 12.5 M.P.H. corresponds to 8.25 M.P.H. between terminals. A similar process gives 14 M.P.H. as actual running time with a rating of 94 per cent of the maximum for the lighter engines.

Economy of Heavy Train Loads. Since the first introduction of railroads there has been a tendency towards increasing the weight of train load. Never, perhaps, has that tendency been more marked than in the past decade. The successful rolling of heavy rails, and the perfecting of the Mikado and Mallet types of locomotives have especially promoted this increase. From 1903 to 1912, the average train load was increased from 391 tons to 509 tons, or 30 per cent, and the tractive power of locomotives in the same period increased from 60,000 lbs. to 80,000 lbs., or 33 per cent. In a series of communications appearing in the *Railway Age Gazette*, April 10, 1914, given by 35 prominent railway officials, the opinion expressed was almost unanimous that the train load would continue to increase to some extent in the future, and indicated that by 1920 the average train load would be 600 tons or more. The following data, Table XXVI, show the tendency in this direction:

TABLE XXVI

INCREASE IN TRAIN LOADS

Railroad.	Average Freight-train Load.	
	1903	1913
A., T. & S F.	280	310
B. & O.	421	620
C. & O.	473	843
C. & A.	361	491
C. Gt. W.	277	450
C., B. & Q.	271	484
C., M. & St. P.	240	357
C. & N. W.	231	348
D., L. & W.	443	660
D. & R. G.	205	305
Erie	406	597
Gt. Northern	447	635
Ill. Cent.	288	407
K. C. So.	255	520
L. V.	486	599
L. & N.	231	295
M., K. & T.	211	243
M. P.	302	373
N. Y., N. H. & H.	218	291
N. & W.	486	764
N. Pac.	326	542
Penna.	527	719
P. & L. E.	951	1241
Seaboard Air Line	176	246
St. L. & S. F.	195	281
So. Pac.	257	389
Southern	257	389
Union Pac.	345	437
Virginian	....	1392
Wabash	302	395

The economy of using heavy engines may result from one or both of two causes: (1) the reduction of fixed charges through decreased construction costs by using steeper gradients, and (2) the decreased operating expenses due to smaller number of trains being required to haul a given tonnage. In regard to the first it may be said that a study of weights and costs of steam locomotives indicates that additional power in engines costs from 50 to 60 per cent of the average cost.

In regard to the second item, assuming that a train load could be doubled by doubling the weight of the locomotive (probably not true from a practical point of view), the calculations in Table XXVII show that the operating expenses would be by no means doubled, but would be increased perhaps 8 or 9 per cent as a whole and somewhat less than 30 per cent in those items directly affected.

TABLE XXVII

EFFECT ON OPERATING EXPENSES OF DOUBLING ENGINE TONNAGE FOR A GIVEN TRAIN TONNAGE

Item.	Per Cent of Total Operating Expense, 1910	Estimated Per Cent Added.	Added Cost. Per Cent.
Ballast	.50	25	.13
Tie	3.01	25	.75
Rails	.92	25	.23
Other track material	1.13	25	.28
Roadway and track	7.53	10	.75
Bridges, etc.	1.71	10	.17
Locomotives (rep., ren., and dep.)	1.61	20	.32
Engine-house expenses	1.56	10	.16
Fuel for road locomotives	10.35	50	5.17
Water for road locomotives	.65	50	.33
Lubricants, etc.	.40	50	.20
Loss and damage, freight	1.25	10	.12
	30.59		8.61

From the above considerations, the economy of using heavy train loads, which may be accomplished by the utilization of powerful locomotives and by improvement in grades and track, is apparent. The effect on operating expenses of increasing the number of trains to carry a given traffic, say $n+1$ trains instead of n, can be determined in a similar manner, that is, by estimating the effect on the various items of operating expense and then determining the total effect. It should be borne in mind that the revenue for transporting a given amount of traffic is constant, and the fewer trains required to conduct the transportation, the greater will be the net earnings. The late Mr. James J. Hill stated the situation very succinctly by saying " Operating expenses are per train-mile while revenues are per ton-mile."

Spacing of Passing Sidings. On single-track railroads, sidings must be provided for the passing of trains, the spacing of such sidings depending upon the density of the traffic and upon topographical conditions. The economic spacing of passing sidings would be such that the cost of delays incident to passing of trains and the fixed charges on the cost of sidings may be a minimum. Sidings should be so spaced that trains operating on a uniform train interval will not be unnecessarily delayed. If the same rate of speed could be maintained over the entire line and trains were dispatched at uniform intervals, this would require the sidings to be uniformly spaced along the track. However, this scheme cannot be exactly followed and the sidings are actually spaced according to the train schedules. In an ideal case where the sidings are spaced uniformly along the track and trains are dispatched in both directions at intervals equal to twice the time required to run between sidings, and if none of these trains are delayed and they proceed with the same average speed, they will pass at the sidings without wait, as shown in the graphical time-table in Fig. 28. Fig. 29 shows the effect of trains

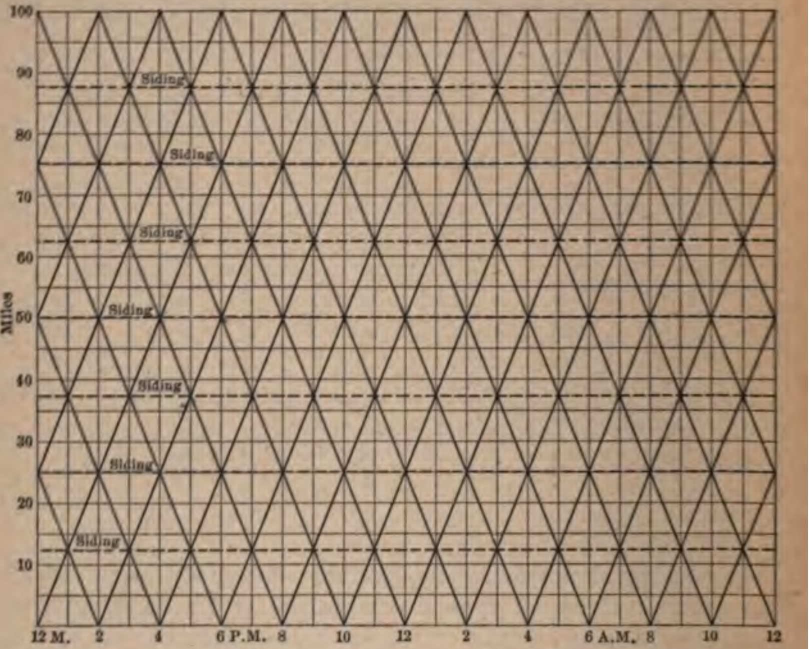


FIG. 28.—Graphical Time-table Showing Uniform Train Interval.

leaving one terminus at intervals a little greater than twice the running time between sidings, causing a delay at each siding, and also the effect of operating different classes of trains over a single track division.

Mr. P. M. LaBach, Asst. Engr. C. R. I. & P. R. R., shows * that the number of passing points required over a division depends largely upon the interval of dispatching trains. If the trains are dispatched at equal intervals, in order that there be no delay, the number of passing sidings would obviously equal the square of the number of round-trip trains per day. If the dispatching is crowded into a certain portion of the day and the trains sent from opposite ends of the division during that period, the number required will be increased, while if the trains are dispatched according to the degree of occupancy of the tracks, the number may be decreased. By constructing graphical time-tables for assumed conditions between these two extremes Mr. LaBach

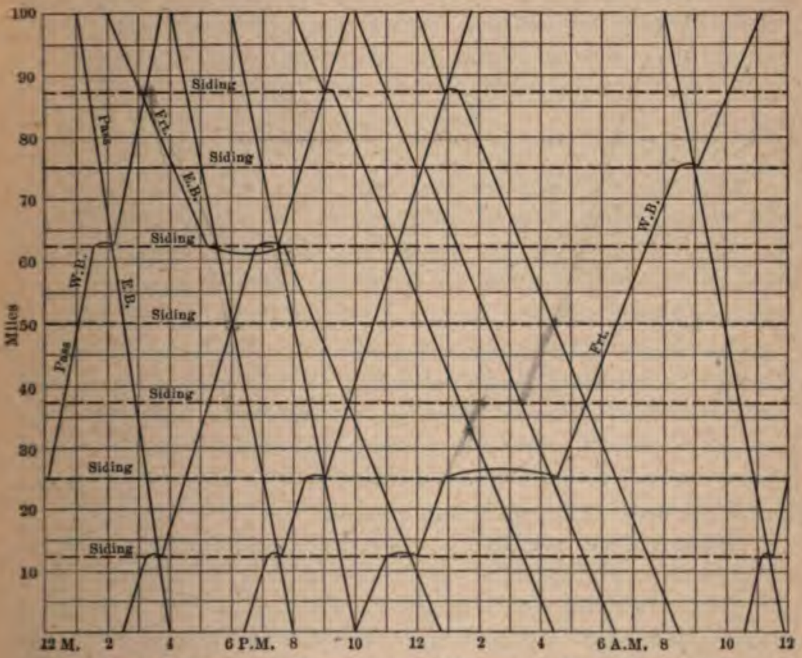


FIG. 29.—Graphical Time-table with Irregular Train Interval.

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* *Railway Age Gazette*, July 30, 1915.

arrives at the results shown below for passenger trains running at 30 M.P.H. and freight trains at 15 M.P.H. over a division 120 miles long.

Number of Trains Each Way per Day.	Square of Number of Trains.	Number of Passings Required.	
		Minimum.	Maximum.
1	1	0	1
2	4	0	6
4	16	0	20
6	36	18	36
8	64	30	71

This demonstration illustrates the interdependence of interval between sidings or the total number of sidings and the dispatching of trains. The economical limit of increasing the number of sidings will be considered in connection with double tracking (See Chapter XX).

Generally water and coaling stations should be placed at sidings. Experience shows that water stations are required about every 15 to 25 miles and coaling stations every 70 miles. The economic limit of increasing the number of these facilities occurs when the cost of such facilities together with the cost of delays in taking water and coal is a minimum.

Spacing of Terminals. The successful operation of a railroad depends to a considerable extent upon the economic spacing of terminals. By terminal is meant a point either at a terminus or an intermediate station where facilities are provided for breaking up, assorting, assembling and classifying trains. Ordinarily train crews are changed at terminals, and inasmuch as the crews are allowed a minimum mileage for each run, it is advantageous to space the terminals at a distance equal to or a little greater than that minimum, which is usually 100 miles. The selection of points for rearranging trains should be made to an extent with reference to the ruling grades; the heavy grades should be grouped into one division where practicable and that division made as short as circumstances will permit. The following discussion of this subject is largely extracted from "Economics of Railway Operation," by M. L. Byers, Chief Engineer of Maintenance of Way, Missouri Pacific Railway.

The length of run must not be so great as to overtax the endurance of the engine and train crews, the fireman being the chief sufferer on long runs; or to cause the fire and ash pan to become clogged with cinders on account of the distance between ashpits.

Engine delays at terminal points are nearly constant. Almost regardless of the length of run, from five to eight hours are necessary for the overhauling of an engine at the terminal on the completion of its run. About three-fourths of this time, which is occupied in ashing, coaling, wiping, inspection, etc., is independent of the length of run, while the remaining quarter of the time, occupied in making light repairs, varies to an extent with the length of the run. Therefore, the greater distance between terminals, the smaller the proportion of time spent inactively by the locomotive, and the less the terminal engine costs per engine-mile.

The same arguments apply to freight cars in regard to loss of time and terminal costs. The low freight-car performance of American railways is one of the most apparent defects in their operation, consequently anything that can be done in the selection of the lengths of divisions and the location of terminals that may help to remedy this condition should be done.

As stated above, the arrangement of division lengths and the location of terminals is intimately connected with the selection of the ruling gradient. A certain ruling gradient is made to apply to one or more divisions and there is no advantage, but rather a useless waste of money, when this ruling grade is extended over *part* of another division. Trains are made up and the engines are rated or loaded to pass over any given division in accord with the ruling grade of that division, hence it is obvious that there is no value in making a low ruling gradient over a part of that division. Moreover, if the advantages of low grade portions are to be realized and the distance over which light tonnage must be hauled reduced to a minimum, the heavy grades must be bunched as far as possible and the location of terminals arranged with reference to the changes in ruling gradient.

Other things being equal, terminals can best be located at the junctions with branch lines, at the crossings with other railways and at points where extensive industries can be developed.

The laws regulating interstate commerce, which limit the length of time trainmen may be on duty to sixteen hours, fix the maximum spacing of terminals at about 100 to 150 miles. On a line with low gradients, easy curves and good roadbed, the terminals may be spaced at greater distances than in the case of inferior alignment and roadbed, because the trains will be able to maintain a higher average speed under the former conditions than under the latter. Passenger divisions are sometimes made equal to two freight engine stages. Because of diversity in operating conditions, it is manifestly impossible to formulate any rule for the proper spacing of terminals, and, moreover, the desirability of locating terminals at large cities, whose location is of course independent of any action of the railway for the most part, would make it impracticable to space the terminals strictly according to the economic interval even if one could be determined. The above general suggestions will therefore suffice for the present purpose.

CHAPTER XIII

RULING GRADIENTS

Definition. All grades on a railroad cause a definite amount of resistance, the amount depending upon the steepness of the gradient, as will be shown in a succeeding paragraph. All grades are, therefore, objectionable to a certain extent, but the attendant objections arise from two very distinct sources, and gradients are classed accordingly. One class of grades, in addition to causing the losses common to all gradients because they offer a certain resistance and therefore cause added work to be done, limits the weight of train that can be hauled over any given division on which it occurs, while the other class incur loss by increasing operating expense directly through augmented wear and tear on equipment, cost of fuel, etc. The first class consists of those grades that are called *ruling gradients.* Ruling grade or gradient may be defined as the grade which, by its length or steepness, limits the weight of train that can be hauled by one locomotive over the division on which it occurs. The second class of grades, or those less than the ruling grade, are termed *rise and fall.* The expense of the second class of grades, rise and fall, depends upon the cost of pulling trains over these grades, while the expense caused by the ruling grade includes the cost of pulling the train up the grade and in addition the cost of operating light trains over the level or nearly level stretches of line occurring between the limiting grades. The disadvantages of the former are much more serious than those of the latter, and will be considered in this chapter, while rise and fall will be taken up at another place.

The ruling grade may or not be the maximum grade on a division. In the event that helper engines are used over the maximum grades, or momentum grades are employed (see next chapter), the next steepest grade becomes the ruling grade. The grades of a division are very definitely related to each other in their effect on operation, and when considered in this connection may be termed the *grade system* of the division.

Grade Resistance. As distinguished from the forms of resistance previously discussed, grade resistance is capable of exact mathematical calculation, being equal to the component of the weight parallel to the track. See Fig. 30. It equals $W \sin a$, or, taking the sine equal to the tangent for small angles of inclination, the grade resistance equals $W \tan a$, or Wp, where p is the gradient expressed in per cent. The rule may be formulated, therefore, that THE GRADE RESISTANCE IS 20 POUNDS PER TON FOR ONE PER CENT GRADE, or otherwise stated, THE PER CENT OF GRADE EQUALS THE RESISTANCE IN POUNDS PER 100 POUNDS. From this the serious disadvantage of heavy grades is at once apparent in so far as total resistance is concerned.

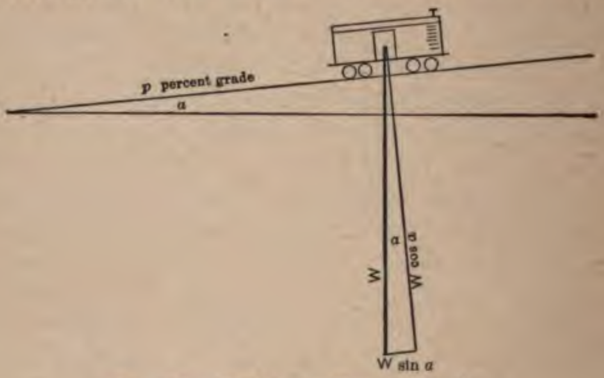

FIG. 30.—Resistance Due to Grade.

A locomotive must perform $20 \times 100 = 2000$ foot-pounds of work in pulling a ton 100 feet along a 1 per cent grade in addition to overcoming other forms of resistance, or the same amount of work as would be done in lifting the ton 1 foot vertically. A locomotive traveling at the rate of 18.75 M.P.H. (27.5 ft. per second) requires $27.5 \times 20 \div 550 = 1.0$ horsepower at the drawbar for each ton it pulls up a 1.0 per cent grade at this rate of speed. However, it is not so much the direct cost of such power that makes heavy ruling grades so objectionable, but rather the fact that this power which must be available wherever the ruling grade occurs cannot be used to advantage over other portions of the line.

From the preceding paragraph, it is evident that grade resistance varies directly with the rate of grade, or $R_g = 20p$. Grade resistance is not the total resistance, however, that must be overcome in ascending any grade, for train resistance as discussed in Chapter XI and curve resistance as will be presented in Chapter XVII obtain on grades as well as on level track, and in the comparison of two grades this fact should be taken into account. For example, assuming a train resistance at 15 M.P.H. of 4 pounds per ton, and a curved resistance of 3 pounds per ton on a 6° curve, then the resistance on a 1.0 per cent grade will be $\frac{20+4+3}{10+4+3}=1.58$ times as hard a pull as on a 0.5 per cent grade under the same conditions, instead of twice as great, or in general terms, $\frac{20G+R+C}{20G'+R+C}$ times as great, where G and G' are the rates of grade in per cent and R and C are the train resistance and curve resistance in pounds per ton respectively. From this, it appears that as the grades increase, the ratio of the total resistances more nearly equals the ratio of the gradients, since the other resistances become a less proportion of the total.

Effect of Grades on Train Loads. The mathematical statement that the load which a locomotive can pull is decreased proportionately with the increase in grade applies to the total load that must be moved by the adhesion of the locomotive drivers to the rails, which includes the weight of the locomotive itself, of the tender and of the caboose. Obviously, the determining condition is the effect of grades upon the *net train load*, or in other words, upon the *revenue-producing train load.* The first question that arises from this consideration is the relation between tractive power and weight of locomotive, including the tender. Table XXVIII gives the relation between the tractive effort and total weight of engine and tender for typical locomotives.

To estimate the effect of grades on train loads, it is necessary to deduct from the tractive power of the locomotive the resistance of the locomotive, the tender and the caboose, for, as stated above, only that portion of the train between the tender and caboose is revenue producing, and it is the effect upon the revenue-producing train that is desired. The tractive effort of most locomotives is known from tests, or it can be estimated with a fair degree of accuracy by assuming a coefficient of friction and multiplying the total weight on the drivers by this coefficient. The coefficient most commonly assumed is

TABLE XXVIII

RATIO OF WEIGHT OF ENGINE AND TENDER TO TRACTIVE POWER

Type of Locomotive.	Total Weight of Engine and Tender, Pounds.	Maximum Tractive Effort, Pounds.	Ratio $\frac{\text{Total wt.}}{\text{Tract. ef.}}$
GAUGE 3 FT. 6 INS.			
American..........	120,000	11,350	10.8
Atlantic...........	150,000	14,180	10.7
Mogul............	153,000	20,200	7.6
Consolidation......	186,000	24,930	7.5
Mikado...........	246,000	28,900	8.5
GAUGE 4 FT. 8½ INS.			
American..........	226,000	22,260	9.5
Atlantic...........	328,000	26,920	11.5
Pacific............	358,000	31,550	12.2
Mogul............	260,000	33,850	7.9
Prairie............	358,000	36,300	9.8
Consolidation......	327,000	41,100	8.0
Mikado...........	491,000	60,800	8.1
Mallet............	752,000	138,000	5.4

¼, although by the use of sand it may be increased to ⅓ and on slippery rails it may not be more than ⅕. For example, consider the Mikado locomotive of the Erie R. R., whose performance is listed in Table XXIX, having a drawbar pull of 44,840 behind the tender on the level at 15 M.P.H. on a 0.5 per cent grade, assuming 3 lbs. per ton as the train resistance.

TABLE XXIX

TRAIN TONNAGE BEHIND TENDER OF ERIE MIKADO LOCOMOTIVE

Figures are Based on Maximum Tractive Power at the Different Speeds, Cars 70 Tons Gross, and a Frictional Car Resistance of 3 Lbs. per Ton on the Level. Weight of Locomotive, 318,000 Lbs.; Tender, 162,700 Lbs.

Speed, Miles per Hr.	Drawbar Pull on Level, Lbs.	0.2 Per cent Grade, Tons.	0.3 Per cent Grade, Tons.	0.5 Per cent Grade, Tons.	0.75 Per cent Grade, Tons.	1.0 Per cent Grade, Tons.	2.0 Per cent Grade, Tons.
5	54,140	7530	5830	3970	2800	2140	1030
10	52,240	7260	5610	3820	2700	2050	980
15	44,840	6210	4800	3260	2280	1740	810
20	37,240	5140	3960	2670	1860	1400	640
25	29,940	4100	3150	2110	1460	1090	470
30	24,540	3340	2550	1700	1160	860	340

Grade resistance of engine and tender $=240\times.5\times20=2400$ lbs. Available for pulling train up grade, $44{,}840-2400=42{,}440$ lbs. Train load that can be pulled $=42{,}440\div(10+3)=3260$ tons. To calculate the revenue train load that could be pulled up a 0.5 per cent grade where the tractive effort of the locomotive has been determined by multiplying the weight on the drivers by the coefficient of friction, or by testing with a dynamometer at a testing plant (see p. 158), the rolling resistance of the engine, tender, and caboose should be deducted also from the drawbar pull in addition to the grade resistance on them. For example, assume the total tractive effort available for the above Erie locomotive to be 45,700 lbs. at 15 M.P.H. Then,

Grade resistance of engine and tender $=240\times20\times.5=2400$ lbs.
Rolling resistance of engine and tender $=240\times3$ $=720$ lbs.
Rolling resistance of caboose (assumed) $=100$ lbs.

Total tare resistance 3220 lbs.

Available for pulling train, $45{,}700-3220=42{,}480$ lbs.

Train load that can be pulled up 0.5 per cent grade $=42{,}480\div(10+3)=3260$ tons.

The tractive effort at any speed can be calculated as shown on p. 154.

To determine the reduction in train mileage resulting from a proposed change in the grade, it is necessary to find, in the manner indicated above, the train load that can be pulled up the two grades and to *compare those train loads.* Thus, if it is proposed to reduce a grade from 0.75 to 0.5 per cent, the train load that can be pulled up the 0.75 per cent grade at 15 M.P.H. by the above engine is 2280 tons. The engine mileage required to haul a given traffic tonnage up this grade would, therefore, be $2280\div3260\times100=70$ per cent of what would have been required for the 0.75 per cent grade, or a reduction of 30 per cent.

From a careful analysis of the effect of changes of gradient upon train loads, Mr. A. M. Wellington formulated the two following laws:

"1. When the rate of any given ruling grade is increased or decreased, the corresponding percentage of increase or decrease in the engine mileage required to handle any given tonnage varies almost directly as the change in the rate of grade, however much or little the change may be, slightly increasing, however, as the increase is greater and decreasing as the decrease is greater.

"2. The amount of this percentage of increase or decrease in the engine tonnage varies considerably with each grade, being nearly five times as much on a level as on a 3 per cent grade."

The laws are still approximately true, perhaps even more nearly so than when first proposed, owing to the decrease in train resistance per ton. Fig. 31 shows the proportion of full tonnage that can be hauled up various grades by an average engine, the level track tonnage being taken as 100 per cent. Ordinarily the changes in ruling gradient which an engineer must consider are not very great, a small fraction of 1 per cent generally, but for best results the effect should be computed in detail.

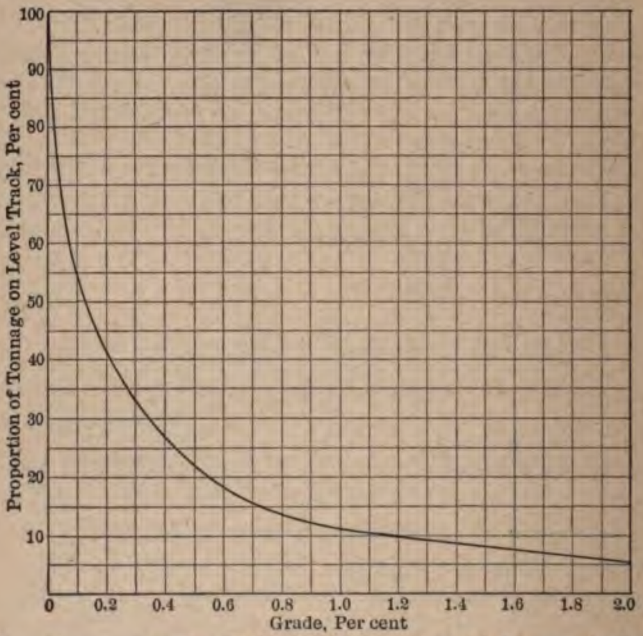

FIG. 31.—Diagram Showing Reduction in Tonnage with Increase in Gradient, Tonnage on the Level being Taken as 100 Per Cent.

Character of Traffic Affected. Where the traffic is light and the train loads are well within the power of the locomotives used, small variations in the ruling grade may have but little influence, but under conditions of dense traffic where the locomotives are loaded to the limit of their capacity, practically all of the traffic is affected. The operation of freight trains is chiefly involved, although heavy passenger trains may also be affected. Obviously the chief objection to a heavy ruling gradient is due to its limiting the weight and length of trains, and a reduction of the ruling gradient has value only when the grade is a limiting factor and not the lack of business. Regular local freights, which make certain runs almost regardless of the amount of freight to be hauled, seldom have their weight or length determined by the ruling grade. Roads on which a large portion of the business is derived from transporting heavy produce, such as lumber, coal, ore, and steel products in large quantities, will be concerned chiefly in making the ruling gradient a minimum.

Because of the higher speed which passenger trains must maintain, passenger locomotives are always loaded with much less than they could actually pull, and hence they operate over the ruling grade with diminished speed, much as a fully loaded freight train passes over a minor grade. Moreover, additional passenger trains are usually put on in order to give more frequent service long before the capacity of the locomotive is actually reached. However, over mountain divisions, the decreased speed due to heavy gradients of considerable length are a serious disadvantage owing to the fact that passenger trains cannot be broken up and reassembled at every division point with reference to the grades of the succeeding division as can freights, and the increased weight of through trains with the heavy modern rolling stock that accompanies the luxurious transcontinental passenger train of to-day make the train that is loaded for plains conditions very difficult to pull over the mountain divisions. Passenger trains leaving Chicago for San Francisco or for Seattle, for example, remain almost unchanged throughout the entire distance regardless of whether they are passing over the prairies of the Mississippi valley or over the Rocky Mountains. Heavier engines, however, are used over the mountain districts.

It is probably true that the ruling grade of most roads that have been constructed has been chosen with a view to the heavier traffic that was anticipated, and this condition should certainly always be kept in mind. While it may be advisable to adopt a rather heavy ruling grade in first construction, owing to the small amount of business immediately in prospect, the possibility of a grade revision in the event of the growth of traffic should constantly be before the eye of the engineer, and the line so chosen that grade revision will not be made impossible.

Effect of the Length of Grade. The length of the ruling grade from practical considerations may be almost as important under certain circumstances as the rate. The following extract from the report of the Committee on the Economics of Railway Location of the American Railway Engineering Association, 1913, states the matter succinctly:

" Primarily it should be said that the effect of the length of a ruling grade depends entirely on what speed it is necessary to make up that grade. Hardly any operating division has more than 40 per cent of ruling grade in either direction. It is generally computed that a train must average ten miles an hour over a division of 100 miles in order to secure the best economy. The question of economical speed will be discussed later, but for the present discussion, ten miles per hour will be used for an example.

"Assume a division with 40 miles of ruling grade, and 60 miles of either downhill or less than ruling grade. If 8 miles per hour is averaged on the ruling grades, and 12 miles per hour averaged on the down grades and less than ruling grades, the run may be made in ten hours. If a grade is very short, following a stretch of either downhill or less than ruling grade, sufficient speed may be had at the bottom to carry the train over the top, even though the ascending grade be considerably more than the ruling grade. As the train goes up the hill its speed will constantly decrease. The speed at the top of the hill must be such that the engine still has some margin between its maximum tractive effort and what is required of it. The result depends entirely upon the speed of the train at the foot of the grade. Such a grade is called a ' Momentum Grade,' and, while most railroad men will say it is not safe to depend upon momentum, it is probable that there is not an important railroad in the country where the locomotive engineers cannot tell of portions of the line that are operated in this manner, even though the officers of the railroad do not know it. Were it not for momentum, it is likely that many curves would prove to be stalling points that are now passed around with not much, if any, trouble. We are learning more every day about handling trains and power at low speeds, but it must be understood that these low speeds are only for use for short periods of time, and not for general practice over a whole run. When the grade is long enough for the train to become stretched out fully upon it, or, in other words, when the engine settles down to a constant speed with its maximum tonnage, the rating speed for that particular train becomes fixed. Without a rise in the steam pressure, the train cannot accelerate as long as the grade remains the same. If there is a large percentage of this character of line on the division, the rating speed must be considerably higher than if there are only one or two places. For instance, it may be possible to average 7 miles per hour over one piece of grade, if that is the only piece on the division, because the difference in time would be made up on the rest of the division, but it would be manifestly improper to load an engine so that such a low speed would be made over the whole run. Not only the low speed, but the constant demand on the engine would be such that the fireman would play out, and failure would be the result."

Proper Percentage of Rating. Practical reasons also limit the rating of a locomotive over any engine district, as stated in the report of the same Committee:

"It has been stated that a locomotive standing on a dry steel rail should be capable of exerting a pull on a spring balance equal to (approximately) one-fourth its weight on drivers. This amount can be increased by the application of some medium to increase the coefficient of friction, such as sand, to about 35 per cent (for momentary purposes only).

"This same pulling power can be used to haul a train, including, of course, the engine and tender itself.

"Ratings in use are never as great as could be pulled by the locomotive utilizing a tractive power of one-fourth the weight on drivers. The reason is apparent. Time is the essence of rating, just as it is the prime factor in all railroading. The governing question is:

"For how long a time must a locomotive be required to exert its maximum pull during any particular run?

"If it is required to exert a maximum effort for only about five minutes at a time, the rating might be established for a maximum effort, provided that time for rest of man and recuperation of fire elapses between the periods of maximum effort.

"If maximum ratings were established for divisions where the ruling grades were long enough to require maximum effort for some time, the following conditions would have to be combated:

"1. Poor draft, owing to slow exhaust.

"2. Poor fire on account of poor and intermittent draft.

"3. Dirty fire on account of imperfect combustion.

"4. Tired fireman on account of heavy work for a long time.

"5. Steam failure.

"6. Stalling.

"This is ordinarily the result of taking steam at full stroke for a long period of time, with a coal-burning engine.

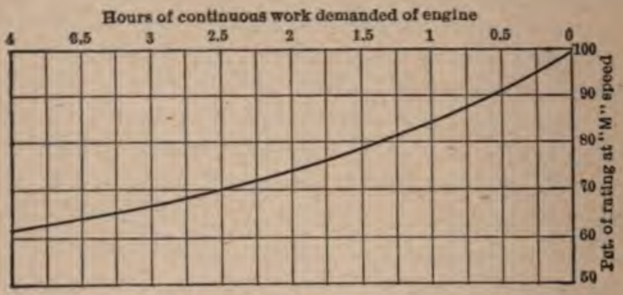

FIG. 32.—Per Cent of Rating of Locomotive.

"It will be understood that, if an engine is adjusted to working under such conditions, an improvement may be had compared with an engine which is utilized on general service.

"The practical problem then is:

"1. How long can the *ordinary* fireman keep his fire in shape to deliver steam at full stroke?

"2. At what rate does his capacity deteriorate?

"3. At what rate can he maintain a steady and consistent performance for long periods of time?

"In order to secure as uniform working conditions as possible, it is necessary to assign values as closely as possible to these rates mentioned.

"The attached plat, Fig. 32, will represent about *what is considered fair practice.* 'M' speed is that speed at which boilers can supply steam at full stroke based on a coal consumption of

4000 lbs. per hour. This diagram is intended to show how much a rating should be reduced on account of continued demand on both fire and machine. The curve shows what is fair practice in this direction.

" In order to apply the chart, find out how long a time it is feasible and practical for the locomotive to consume in ascending the ruling grade, and taking that time on the chart, follow up the line and see what percentage of full rating may be given the engine. It is evident that when the percentage of rating gets as low as 60, it would pay to keep a full rating for the ruling grade with an assisting engine to avoid penalizing all the rest of the run improperly.

" When the ruling factor in the operation is to conserve power, the greatest number of ton-miles per engine-mile is the figure to work for. This, however, will not always produce the lowest cost per ton-mile. At times there is a shortage of train crews and a surplus of power. In this case it becomes imperative to make the greatest number of ton-miles per train-mile. This nearly always shows the greatest economy of movement."

Choice of Ruling Gradient. The choice of ruling gradient is made by balancing the cost of operation over a given gradient against the cost of reducing it, and the economic gradient will be the one that will make the sum of these two items a minimum. That is, the total cost of interest on initial cost plus operating expenses over the division should be a minimum.

Two considerations must be taken into account in determining the rate of ruling gradient to be adopted, namely, (1) the selection of the economic ruling gradient for any one division and (2) the relation of operating conditions over this division to those existing on the remainder of the line. Where different ruling gradients on adjoining engine divisions are unavoidable, due consideration must be given to the cost of breaking up and reforming trains at the division points, for the trains must be made up with respect to the grades occurring on the succeeding division. The selection of the proper ruling gradient, as stated above, is entirely a question of economics, and the degree of correctness attained in the result will depend upon the completeness and accuracy of the data upon which the solution is based, including the accuracy of the estimate of the quantity and class of the traffic to be handled and the care with which the surveys are made.

As stated previously, railroad location is the problem of designing the most economical transportation plant to fit the conditions given. The plant should not be more expensive than the conditions justify, nor should it be inadequate to meet the needs of the situation. Thus, error and poor design may arise from an attempt to use too low a ruling gradient as well as from the use of one too steep.

Where a given elevation is to be overcome, extensive development introducing great distance may be a mistake, for the work done, the fuel consumed, and the increased maintenance in passing over this distance may amount to more than increased cost of operation over a heavier gradient, especially if the traffic expected is more or less problematical and the ruling gradient that can be obtained over the shorter route is at all a reasonable one.

In the choice of ruling gradient, some consideration should be given to future possible revisions of the line. To illustrate this point, cases might be cited where it has been necessary to abandon practically the entire line in order to secure a needed grade reduction, whereas on other locations, a comparatively small amount of work in raising track at low places and lowering it at others, the construction of a tunnel, or a shift of a short stretch of line has given the needed improvement. A proposed route may be a low gradient location with the exception of a short portion which can be made to conform to the remainder of the line when the traffic shall have become sufficient to justify the necessary expenditure. In this respect, the possibilities of future grade revision should be kept in mind in the original location.

Wellington formulated the following rule for the selection of grades: " Follow that route which affords *the easiest possible grades for the longest possible distances*, using to that end such amounts of distance, curvature, and rise and fall as may be necessary, and then *pass over the intervening distances on such grades as are then found necessary.*

Estimating the Value of Grade Reduction. In the consideration of any particular case involving a comparison of two or more proposed grades, it is necessary to determine as nearly as possible the effect of each case on operating conditions. In comparing the effect of these grades, it is necessary to take into consideration all of the elements that enter into the problem. The grade resistance must be added to the ordinary train resistance and curve resistance, inertia resistance. The amount of these resistances has been discussed at another place. The first question to be answered is, What will be the effect on the train-mileage required to handle a given amount of traffic?

The ratio of the total resistance on the two grades will be

$$\frac{20G'(W_e+W_t)+R_e+R_t+C}{20G(W_e+W_v)+R_e+R_t+C}$$

where G and G' are the per cents of grades, W_e and W_t the weights in tons of engine and train respectively, R_e and R_t the resistances in pounds of engine and train respectively, and C the resistance in pounds due to curvature. The effect on operating expenses of an increase in train mileage for a given traffic is shown in Table XXVII.

The effect of any change in grade on cost of operation may be estimated by an analysis of operating expenses in a manner similar to that used previously. Table XXX shows the cost per train-mile for an additional train that may be required because of heavier grades to handle a given tonnage. From this table, it appears that the cost of an additional train would be on the average, $1.76×.3431 = $.604. Adding $.02 for interest on the additional engine and caboose, gives $.624 as the average cost per train-mile for the additional train. This is on the assumption of $1.76 as the cost per train-mile. While this is the average cost for the year 1914, the actual cost for the road in question should be used where data are available, or otherwise that of a similar road in like territory should be employed. By reducing the gradient so that the traffic can be handled by any number of trains less per day, the effect on operating expenses can thus be estimated, and the saving computed. This sum capitalized will indicate the amount that might be justifiably spent in making the change.

For example, suppose that the grade on a tangent is to be reduced from 1.0 to 0.75 per cent and is to be operated by the Erie engine mentioned on p. 222, the speed to be 10 M.P.H. The reduction in train mileage required to handle a given amount of traffic is found to be 2250÷2700 = .76 of that previously required, or a saving of 24 per cent. Thus, on a 100-mile division with 15 trains each way per day, this would mean a saving

2050

of \$.624×100×2×365×15×.24=\$164,160. This, capitalized at 6 per cent amounts to \$2,736,000, the sum that might be justifiably spent in making the change.

TABLE XXX

COST PER TRAIN-MILE FOR AN ADDITIONAL TRAIN TO HANDLE A GIVEN TONNAGE

Item.	Average Cost, Per cent.	Proportion Affected, Per cent.	Cost of Additional Train per Train-mile, Per cent.
Ballast	.33	10	03
Ties	3.07	25	77
Rails	.88	25	22
Other track material	.99	25	.25
Roadway and track	6.85	10	.69
Bridges, etc.	1.69	10	.17
Other M. of W. expenses	5.06	5	.25
Steam locomotives	9.34	75	7.03
Dispatching trains	.85	10	.08
Yard crews	2.83	50	1.41
Yard enginemen	1.64	50	.82
Yard locomotives	1.73	25	.43
Road enginemen	5.95	100	5.95
Enginehouse expenses	1.73	75	1.30
Fuel for road locomotive	9.42	75	7.07
Water, etc.	.98	75	.74
Train supplies	1.84	75	1.38
Interlocks and signals	.53	25	.13
Other transportation expenses	22.69	25	5.69
Total	51.65		34.31

Light Traffic Railways. The ruling gradient as defined in this chapter has very little significance on light traffic railways, that is, on railways over which the practical minimum number of trains can readily carry the traffic. This statement applies to electric interurban railways for passenger service also. In the latter, the value of high speed must be balanced against the fixed charges involved in reducing gradient, and in the case of light traffic steam railways the chief objective is to select grades than can be ascended, even at low speed, by the light trains that are to be operated and to keep maintenance of way expenses a minimum. Maintenance of Way and Structures is a much larger percentage of the total operating expense on small roads than on large. The difference in the operating and maintenance costs of a heavy locomotive required to pull the light train over the steeper grades and of a lighter locomotive that might be required over easier grades is but trifling.

Many branch lines which serve a thinly populated and poorly productive region are required for various reasons to run perhaps one freight train and one passenger train each way per day, or at least one mixed train each way, and neither of these has any difficulty in carrying all the traffic that is offered. Under such circumstances, the ruling gradient does not in any way limit the weight or length of train that can be operated over the division. Many such branch lines have been built in the past, as some one has rather facetiously remarked, "following grass roots for grade and local subsidy for line," and have served to build up the communities and still serve as feeders to main line roads.

Another class of light traffic branch lines are those built from main line roads into more populous regions that are served chiefly by other roads to connect the main line with such regions in order to handle directly such business as may originate at such points. It is frequently impracticable for the main line of a railroad to reach a center of population which may offer considerable business, but which may be 10 to 50 miles away from the right of way. Again, such a community may grow up after the railroad is located and it may become desirable to construct a tap line to it for such business as it may offer. Under such circumstances, the light traffic railway is built and operated without any great expenditure in attempting to reduce ruling gradient, for the traffic in all probability will never be such that the trains will be limited in any sense by the ruling grade.

Grades on Sidings. When on single-track lines sidings are placed on maximum grades, care must be exercised to reduce the grade on the sidings below the ruling gradient lest trains loading for the ruling gradient should stall with their load while pulling from the siding on to the main line, owing to the fact that train resistance is much greater at starting after a train has been standing for some time than after it has been in motion a while. The resistance of starting should be taken as 15 to 20 lbs. per ton in calculating the proper rate of reduction on the siding. The grade at the lower end on the siding can be made greater to compensate for the decreased rise in the upper end, for the only effect of steeper grade at the entering end is to assist the train to stop by offering some of the resistance that would otherwise have to be furnished by the brakes. This increased grade resistance at the lower end may be overcome by the velocity head that the train has on entering the siding and which would have to be overcome anyhow by the brakes when coming to a stop on the siding.

CHAPTER XIV

MOMENTUM AND MINOR GRADES

Theory of Kinetic Energy. The underlying principles of kinetic energy were briefly outlined in Chapter XI in connection with inertia resistance to the motion of trains. It will be recalled that the principle was established that the work done on a body by a force equals the increment of energy stored in the body by virtue of that work and in the event that all of the increment of energy is kinetic, the work done equals the increment of kinetic energy. That is,

$$F.s=\frac{1}{2}\frac{W}{g}(v_2{}^2-v_1{}^2)+\frac{1}{2}\frac{w}{g}k^2(\omega_2{}^2-\omega_1{}^2),$$

the first term representing the energy in translation of the entire train, and the second the energy of rotation of the wheels. It was also shown that the second term on the average amounts to about 5 per cent of the first, and hence the total kinetic energy of a moving train amounted to $\frac{W}{2g}v^2\times1.05$, and the amount of work that can be done by the train by virtue of its velocity equals this quantity. If the work that a body performs by virtue of its velocity consists in lifting its own weight a certain height, h, that height would be found by equating the work done to the energy, thus, $Wh=\frac{W}{2g}v^2$, or $h=\frac{v^2}{2g}$. That is, a body having a velocity of v feet per second would rise by virtue of this velocity to a height equal to the velocity squared divided by twice the gravity acceleration constant. The quantity, $\frac{v^2}{2g}$, is sometimes called the "velocity head" and is a familiar term in hydraulics and other problems in dynamics. For a train the velocity head should be increased 5 per cent on account of the rotative energy of the wheels, as stated above, and when thus increased and reduced to terms of miles per hour instead of feet per second, the velocity head becomes $0.03511V^2$. Ignoring friction, a train would ascend a grade until it reached a height equal to the velocity head before coming to a stop. This principle of velocity head and height of ascent is used frequently in the solution of problems of grades on railroads. Table XXXI gives the velocity heads or values of $0.03511V^2$ for velocities from 1 to 50 miles per hour.

Use of Momentum. A body in motion will continue in motion with an unvarying velocity so long as the externally applied forces are in equilibrium, according to a well-known principle of mechanics. Thus, a train pulled by a locomotive will continue at a uniform speed if the locomotive exerts just enough force on the drawbar to overcome the total train resistance. Under such conditions, the train is moving as if not acted upon by any external forces. With a given velocity, therefore, the train would be able to ascend a grade to a height, h, equal to $0.03511V^2$ by virtue of this velocity and it would have zero velocity when it attained this height. This energy may be dissipated by allowing the train to run against ordinary rolling resistance on the level, or by applying a retarding force by means of the brakes. On the other hand, the energy that a train has by virtue of its velocity may be used in conjunction with the pull of the locomotive to carry the train up a grade. Thus, if a locomotive has sufficient power to pull its train up a G per cent grade of a given length at a uniform velocity, theoretically it will pull it up a grade of $G+0.03511\ \frac{(V_0^2-V_1^2)}{L}$ per cent of the same length, if the velocity is reduced in the ascent from V_0 to V_1, L being the length of the grade in 100-foot stations.

In addition to the kinetic energy stored in a train having a given velocity, the locomotive of the train that has been running on the level or on descending grades has considerable excess energy stored in its boiler due to increased steam pressure and to dryer steam. This "boiler momentum" is not capable of exact analysis and very few experiments have been made to determine its amount, but its existence is commonly recognized. On the other hand, the stored energy due to the velocity of the

TABLE XXXI

VELOCITY HEADS

Velocity, M.P.H.	00.	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	.....	.....	.....	.....	.....	.....	.....	.....	.01	.02
1	.03	.04	.05	.06	.07	.08	.09	.10	.11	.13
2	.14	.15	.17	.19	.20	.22	.24	.26	.28	.30
3	.32	.34	.36	.38	.40	.43	.46	.48	.51	.54
4	.56	.59	.62	.65	.68	.71	.74	.78	.81	.84
5	.88	.92	.95	.99	1.02	1.06	1.10	1.14	1.18	1.22
6	1.26	1.31	1.35	1.40	1.44	1.48	1.53	1.58	1.62	1.67
7	1.72	1.77	1.82	1.87	1.92	1.97	2.03	2.08	2.14	2.19
8	2.25	2.30	2.36	2.42	2.48	2.54	2.60	2.66	2.72	2.78
9	2.84	2.90	2.97	3.04	3.10	3.17	3.24	3.31	3.38	3.44
10	3.51	3.58	3.65	3.72	3.79	3.87	3.95	4.02	4.10	4.17
11	4.25	4.33	4.41	4.49	4.57	4.65	4.73	4.81	4.89	4.97
12	5.06	5.15	5.23	5.32	5.41	5.50	5.58	5.67	5.75	5.84
13	5.93	6.02	6.12	6.21	6.31	6.40	6.50	6.59	6.69	6.78
14	6.88	6.98	7.08	7.19	7.29	7.39	7.49	7.60	7.70	7.80
15	7.90	8.00	8.11	8.22	8.33	8.44	8.55	8.66	8.77	8.88
16	8.99	9.10	9.21	9.32	9.43	9.55	9.67	9.79	9.91	10.03
17	10.15	10.27	10.39	10.51	10.63	10.75	10.87	10.99	11.12	11.25
18	11.38	11.50	11.63	11.76	11.89	12.02	12.15	12.28	12.41	12.55
19	12.68	12.81	12.95	13.08	13.22	13.35	13.49	13.63	13.77	13.91
20	14.05	14.19	14.33	14.47	14.61	14.75	14.89	15.04	15.19	15.34
21	15.49	15.64	15.79	15.94	16.09	16.24	16.39	16.54	16.69	16.84
22	17.00	17.15	17.30	17.46	17.62	17.78	17.94	18.10	18.26	18.42
23	18.58	18.74	18.90	19.06	19.22	19.38	19.55	19.72	19.89	20.06
24	20.23	20.40	20.57	20.74	20.91	21.08	21.25	21.42	21.59	21.77
25	21.95	22.12	22.30	22.48	22.66	22.84	23.02	23.20	23.38	23.56
26	23.74	23.92	24.10	24.28	24.46	24.65	24.84	25.03	25.22	25.41
27	25.60	25.79	25.98	26.17	26.36	26.55	26.74	26.93	27.13	27.33
28	27.53	27.73	27.93	28.13	28.53	28.53	28.73	28.93	29.13	29.33
29	29.53	29.73	29.93	30.13	30.34	30.55	30.76	30.97	31.18	31.39
30	31.60	31.81	32.02	32.23	32.44	32.65	32.86	33.08	33.30	33.52
31	33.74	33.96	34.18	34.40	34.62	34.84	35.06	35.28	35.50	35.72
32	35.95	36.17	36.39	36.62	36.85	37.08	37.31	37.54	37.77	38.00
33	38.23	38.46	38.69	38.92	39.15	39.38	39.62	39.86	40.10	40.34
34	40.58	40.82	41.06	41.30	41.54	41.78	42.02	42.26	42.61	42.76
35	43.01	43.26	43.51	43.76	44.01	44.26	44.51	44.76	45.01	45.26
36	45.51	45.76	46.01	46.26	46.52	46.78	47.04	47.30	47.56	47.82
37	48.08	48.34	48.60	48.86	49.12	49.38	49.64	49.91	50.18	50.45
38	50.72	50.99	51.26	51.53	51.80	52.07	52.34	52.61	52.88	53.15
39	53.42	53.69	53.96	54.23	54.51	54.79	55.07	55.35	55.63	55.91
40	56.19	56.47	56.75	57.03	57.31	57.59	57.87	58.16	58.45	58.74
41	59.03	59.32	59.61	59.90	60.19	60.48	60.77	61.06	61.35	61.64
42	61.94	62.23	62.52	62.82	63.12	63.42	63.72	64.02	64.32	64.62
43	64.92	65.22	65.52	65.82	66.12	66.42	66.74	67.05	67.36	67.67
44	67.98	68.29	68.60	68.91	69.22	69.53	69.84	70.15	70.46	70.78
45	71.10	71.42	71.74	72.06	72.38	72.70	73.02	73.34	73.66	73.98
46	74.30	74.62	74.94	75.26	75.59	75.92	76.25	76.58	76.91	77.24
47	77.57	77.90	78.23	78.56	78.89	79.22	79.55	79.89	80.23	80.57
48	80.91	81.25	81.59	81.93	82.27	82.61	82.95	83.29	83.63	83.97
49	84.32	84.66	85.00	85.34	85.69	86.04	86.39	86.74	87.09	87.44
50	87.79	88.14	88.49	88.85	89.20	89.55	89.91	90.26	90.61	90.97

train and the additional steam cannot be spread out uniformly over a long, steep grade owing to the various losses that occur. For instance, a train running from A to B several miles apart with the engine working steam all the way will have about the same velocity on reaching B whether it started from rest or with an initial velocity.

From the beginning, practical railroad men appreciated the advantage obtained by " making a run for a hill " and the concomitant difficulty of starting after a stop on a grade. As seen from the above discussion, the amount of this practical advantage is capable of fairly exact calculation. To a certain extent, it is considered good practice to take advantage of the effect of velocity head in determining the ruling gradients, particularly in difficult country on light and medium traffic railroads. With this in mind, the ruling gradient would become the one that makes the maximum actual demand upon the locomotive. *Momentum grades*, that is, those grades that are surmounted partially by means of the velocity head that the train has at the bottom, may be used, although they are actually steeper than what would under normal conditions of operation be the ruling gradient. Momentum grades should not in any case exceed that up which the locomotive can handle its train in two sections, in the event that it is forced to stop in the sag or for any other reason is unable to approach the grade with the velocity necessary to reach the summit. Obviously, the length of a momentum grade is as important as its rate, for either represents an amount of energy consumed.

A rule given in the report of the Committee on Economics of Railway Location of the American Railway Engineering Association in 1914 states.

" In the calculation of the length of momentum grades, the maximum speed of freight trains at the bottom of the sag should not exceed the speed limit for such trains on the engine district under consideration, and the minimum speed at the top of the grade, where the velocity grade joins an ascending grade of any considerable length, should not be less than 11 miles per hour and the minimum speed on summits should not be less than 9 miles per hour."

Feasibility of Momentum Grades. In the past, locating engineers have frequently made use of momentum grades in the design of railway locations, but modern conditions of traffic make it inadvisable generally to count on momentum as a necessary factor in overcoming grades that are heavier than the established ruling gradient. This statement applies particularly to busy lines. A block signal, a water station, a snow drift, or any number of other causes for occasional stops might prevent the full realization of the effect of momentum and a blockade of traffic might result. On heavy traffic lines such a blockade of the movement of trains would be a serious matter owing to the direct loss of time and the indirect moral effect on business.

Momentum grades should not, therefore, be used as an expedient for cheapening construction, but rather as a last resort in overcoming a bad condition of topography. A location designed without counting on the use of momentum will be all the more satisfactory when momentum is available in the practical operation of the line, and the loss resulting from the failure to utilize the effect of momentum in the original design will not be more than might be expected in providing a factor of safety by any other means. In grade reductions on an existing line, however, it may happen that momentum grades can be used to advantage owing to the nature of the route originally selected.

7 **Virtual Gradient and Virtual Profile.** In view of the foregoing discussion, it is obvious if a locomotive is required to accelerate its train, it is, in effect, overcoming additional grade resistance and the effectual gradient is greater than the actual grade, and conversely, if the train is slackening its speed, the effectual gradient is less than the actual grade. Thus if a locomotive starting from rest, say at a station or at a water tank, gives its train a velocity of 30 M.P.H. in going half a mile, it effectually lifts the train an additional 31.60 ft. in that distance, or adds 1.2 per cent to the grade. If the train had started from the station on a down grade of 1.2 per cent, it would have attained the speed of 30 M.P.H. without the locomotive exerting a drawbar pull greater than that necessary to overcome ordinary train resistance. If a train with a velocity of 30 M.P.H. should approach the bottom of a 1.0 per cent grade 1000 ft. long, it could arrive at the top by losing 10 feet of velocity head, or having its velocity reduced to 24.8 M.P.H. without the engine's exerting any force on the drawbar other than that required to overcome rolling resistance of the train.

The locating engineer is chiefly concerned, therefore, with the actual demand on the locomotive rather than the gradient which the profile may show. The gradient that is actually overcome by the locomotive is called the *virtual gradient* and the *virtual profile* is the succession of virtual gradients. The virtual profile may be widely different from the actual profile and should be very carefully investigated. It is not a succession of straight grade lines similar to the actual profile, but is a succession of vertical curves, owing to the variation in the drawbar pull of the locomotive and of train resistance with the speed, resulting in a non-uniform variation in the velocity and consequently in the velocity head. In general, the virtual profile is the same as the actual profile when the train is standing or moving at constant speed, and it leaves the actual profile when the speed increases and approaches it as the speed decreases. After the virtual profile is once established no further allowance can be made, and the maximum virtual grade will be absolute in limiting the weight and speed of the train.

The virtual grade will be in general, $G-\frac{(h_1-h_0)}{L}$, G being the actual per cent of grade, h_0 and h_1 the initial and final velocity heads, and L the length of the grade in 100-ft. stations. For example, if the velocity drops from 20 to 15 M.P.H. in ascending 2000 ft. of 0.6 per cent grade, the virtual grade will be $0.6-\frac{14.04-7.90}{20}=0.29$ per cent.

Locomotive Speed Characteristics. If a locomotive could deliver a constant drawbar pull regardless of the speed and if the train resistance remained unchanged when the speed varied, a train might be operated over undulating grades with the same facility as on the level, merely storing up energy on the down grades and paying it out again on the up grades. As has been indicated in previous chapters, neither of these conditions actually obtain. For a constant horsepower output, the tractive effort varies inversely as the speed, or $V \times T=$ a constant. As shown in Fig. 33, there is a certain range of rate of piston travel that permits the maximum power output, varying usually from 700 to 1000 ft. per minute, and hence, operation is most efficient at these speeds. The drawbar pull decreases after speed M (piston speed of 250 ft. per minute in Fig. 33) and the drawbar pull at any other speed is found by multiplying the drawbar pull at M by the speed factor in per cent for the given speed. The tractive effort at any speed depends, therefore, upon the steaming capacity of the boiler to a great extent, and ultimately upon the heating surface available. One prominent manufacturer designs locomotives on the basis of 1 horsepower at the tread of the drivers at running speeds for every 2.5 sq. ft. of heating surface. Whatever this ratio, it is manifest that the tractive effort at various speeds is directly dependent upon the capacity of the boiler.

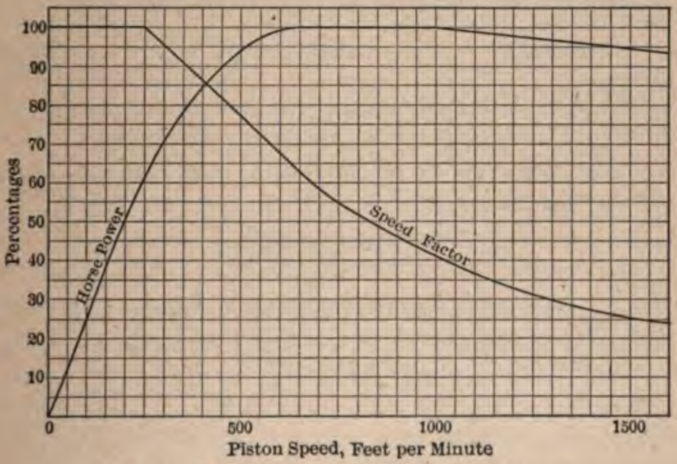

FIG. 33.—Speed Factor and Horsepower Curves.

Since a locomotive cannot produce steam at a rate to keep pace with the demand at high speeds, the cut-off is shortened for high velocities, thereby shortening the period in which steam enters the cylinders, allowing the steam to expand to a greater extent and hence decreasing the amount used per stroke. This shortened cut-off produces less work in the cylinders per stroke and consequently decreases the tractive power at the drivers.

Length of Momentum Grades. Since the energy stored in the train may be expended in doing work, this work may be distributed, theoretically at least, over the length of the grade, the tractive power of the locomotive and the effective force resulting from the loss of velocity being added directly to pull the train up the grade. As a matter of fact, owing to the variableness of the tractive power of the locomotive and of train resistance, there are certain limitations to such a combining of forces. When the theory of momentum grades was first developed and explained, the mistake was made in assuming that the stored energy could be spread out indefinitely over a long grade, whereas, on the contrary, the final speed at which the train arrives at the top of a long grade is almost independent of the speed at the bottom. From formulas previously developed, the distance that a train can proceed up any grade by virtue of its velocity may be determined theoretically by the equation, $s=\frac{70.4(V_1^2-V_2^2)}{F}$, where V_1 and V_2 are the velocities at the beginning and the end of the stretch and F is the net tractive force available per ton. Since the tractive force varies continuously, this equation could be stated more accurately as,

$$s=70.4\int_{V_2}^{V_1}\frac{2V\,dV}{F_V},$$

F_V being the net pull available for accelerating the train.

Taking increments of speed of 1 M.P.H., such a summation between the limiting speeds can be readily made. For example, with the following assumptions as to tractive effort and resistance, for a 1.0 per cent grade, the calculations may be illustrated as shown for speeds between 25 and 21 miles per hour.

Velocity M.P.H.	Total Tractive Force, Lbs. per Ton.	Train Resistance, Lbs. per Ton.	Grade Resistance, Lbs. per Ton.	Net Tractive Force, Lbs. per Ton.	Distance s Feet.
25	6.2	6.0	20	−19.8	178.0
24	6.5	5.9	20	−19.4	174.5
23	7.0	5.7	20	−18.7	173.0
22	7.6	5.5	20	−17.9	173.0
21	8.2	5.2	20	−17.0	174.0
Total distance in change from 25 to 21 M.P.H.					872.5

For approximate calculations, the tonnage that can be pulled up any grade, G per cent, with a change of speed from V_1 to V_2 is obviously,

$$T=\frac{P_aL}{(R+20G)L-.71(V_1^2-V_2^2)},$$

and the length of grade in which the speed will be reduced from V_1 to V_2 is, by transposition,

$$L = \frac{.71(V_1^2 - V_2^2)}{R + 20G - \frac{P_a}{T}},$$

in which L is the length of the grade in 100-ft. stations, R, the train resistance in pounds per ton, and P_a, the average tractive force for the two speeds.

In certain grade reduction problems, it may be desirable to calculate the length of grade up which the train will run with a given reduction in speed and to begin at that point to reduce the remainder of the grade, or to count the remainder as rise and fall, for it is well established by experience that momentum cannot be spread out indefinitely over a long grade.

Some engineers have attempted to limit the use of momentum grades by ascribing a limit to the total rise of the grade, such limit usually being set at about 120 ft. of total ascent. The futility of attempting to set such a limit is apparent when it is realized that length of grade is a factor as well as the total rise. It is impossible, also, to state a definite limit to the length of grade up which momentum might be considered as being effective. The safe velocity at the bottom depends upon the character and condition of the track, but in general it is about 30 M.P.H. for freight trains, corresponding to a velocity head of 31.6 ft. Since the velocity should not be reduced below about 10 M.P.H. (velocity head of 3.5 ft.), theoretically, some 28 ft. might be utilized in overcoming gradient. The amount of velocity head that can actually be realized is doubtless somewhat less than this amount owing to the losses inherent in such operation, viz., increased train resistance and impact of buffers. Tests made by the University of Illinois indicate that the train resistance averages about 20 per cent higher at 30 M.P.H than at 12 M.P.H. Assuming train resistance 2 lbs. per ton higher at 30 than at 12 M.P.H., for cars of 35 tons gross weight, the energy lost would be 25 to 30 per cent per mile passed over at the higher speeds. Owing to the slackening of the train from the front causing the buffers of the cars to strike each other, more or less energy is dissipated, amounting under average conditions to perhaps 1 to 5 per cent per mile passed over. From these considerations, it would seem that the velocity head that can actually be realized on a momentum grade would be about 30 to 35 per cent less than the theoretical for every mile of length of grade.

Velocity-Distance Curves. The application of the principle of momentum gradients to the practical tonnage rating of locomotives in the make up of trains was first explained by Mr. A. M. Wellington, but for a number of years after the appearance of his work very little attention was paid directly to the subject. More recently, Mr. A. C. Dennis presented an illuminating discussion * of the subject from which the following abstract is taken.

It is assumed that freight train resistance is constant for speeds between 5 and 35 miles per hour, as tests seem to indicate to be the case, amounting to 9.0 lbs. per ton for empty cars and 4.7 lbs. for loaded cars on a rigid roadbed. The tare weight, or the weight of cars, is reduced to terms of the "rating-ton," which represents a ton of freight in a box car. Further, assuming that for certain conditions of operation the tare weight is one-third of the gross, the tractive resistance per rating-ton is found to be 2.6 lbs. per ton. The reduction factor for converting tare-tons to rating-tons depends upon the rate of ruling gradient for which the locomotive is loaded. For example, to reduce tare to rating-tons for a 0.4 per cent gradient,

A tare-ton has 9 lbs. rolling and 8 lbs. grade resistance = 17.0
A rating-ton has 2.6 lbs. rolling and 8 lbs. grade resistance = 10.6

Hence the total resistance of the tare-ton is $17.0 \div 10.6 = 1.60$ times the resistance of a rating-ton. Therefore, to reduce tare to rating-tons for a 0.4 per cent grade, multiply the tare-tons by 1.60, and a similar factor can be determined for any other rate of grade.

tract-effort

Fig. 34 shows the drawbar pull of a certain consolidation locomotive. At 7 miles per hour, on a 0.4 per cent grade, the rating of this locomotive is equal to the tractive power at this speed taken from the curve divided by the resistance per ton on this grade, or $28{,}200 \div 10.6 = 2660$ gross rating-tons for the train. The gross tons less the equivalent rating-tons of the locomotive and tender (actual weight 130 tons) equals the net

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* Trans. Am. Soc. C. E., Vol. L., p. 1.

1.6

tons for the train behind the tender, or $2660-130\times 2.6=2452$ rating-tons behind the tender. To convert this to actual tons since one-third of the total weight was assumed to be tare, it is necessary to multiply by the factor $\frac{3}{(2+1.6)}$, which would give 2043 actual tons behind the tender.

The tractive power at any given speed divided by the gross rating tonnage gives the tractive power available per ton. From this, subtract the train and gravity resistance and the remainder will be the force available for accelerating the train, which, if positive, will indicate positive acceleration, and if negative, will indicate retardation. With this force known, by a well-known principle of mechanics that the work done on a body equals the increment of energy, the distance required to effect any change in speed may be calculated. Thus, if P is this residual force and s the distance required to effect the change in velocity,

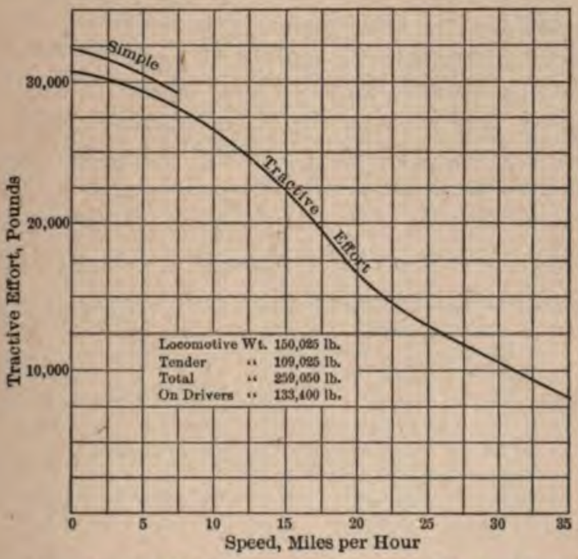

FIG. 34.—Tractive Effort of a Locomotive at Various Speeds.

$$Ps=1.05\frac{2000}{2g}(v_1^2-v_0^2), \quad \text{or} \quad s=\frac{2000}{P}(h_1-h_0),$$

h_1 and h_0 being the velocity heads.

For example, on a +0.2 per cent grade, the distance required to attain a velocity of 11 M.P.H. from 10 M.P.H may be found as follows: The available accelerating force is

$$26{,}400-2660\times2.6-2660\times4=8840 \text{ lbs.}$$

403

$$s=\frac{2660\times2000}{8140}(4.25-3.51)=484 \text{ ft.}$$

Tables were prepared from which the curves shown in Fig. 35 were plotted, using total distances passed over as ordinates and velocities in miles per hour as abscissæ. This diagram is for the locomotive rated for a −0.4 per cent grade only, although other curves were given in the original article and the scheme might be generally applied. A method of tabulating the calculations is shown in Table XXXII.

X

TABLE XXXII

CO-ORDINATES FOR VELOCITY-DISTANCE CURVES

Velocity, M.P.H.	Tractive Power, Lbs.	Tractive Power Less 17,560 lbs.	Velocity Head, Ft.	Difference in Velocity Heads, Ft.	Increments of Distance, Ft.	Total Distance, Ft.
1.......	30,300	12,740	0.3	0.03	12	12
2.......	30,000	12,440	0.14	0.11	47	59
3.......	29,800	12,240	0.32	0.18	78	137
4.......	29,400	11,840	0.56	0.24	108	245
5.......	29,000	11,440	0.88	0.32	149	394
6.......	28,700	11,140	1.26	0.38	182	596
7.......	28,200	10,640	1.72	0.46	230	806
8.......	27,600	10,040	2.25	0.53	280	1086
9.......	27,000	9,440	2.84	0.59	333	1419
10.......	26,400	8,840	3.61	0.67	403	1822
11.......	25,700	8,140	4.25	0.74	484	2306
12.......	24,900	7,340	5.06	0.81	588	2894
13.......	24,000	6,440	5.93	0.87	720	3614
14.......	23,100	5,540	6.88	0.95	913	4527
15.......	22,200	4,640	7.90	1.02	1170	5697

5

The quantities in the last column, total distances, are plotted as ordinates with those of the first, velocities, as abscissæ, for the acceleration curves. Similar data are prepared for the retardation curves, the distance being that passed over in changing the speed from 30 M.P.H. to the velocity in question. On any grade greater than level, the locomotive cannot maintain a speed of 30 M.P.H., hence on any positive grade there will be a retardation. For example, in changing from 30 M.P.H. to 29 M.P.H. on a +0.4 per cent grade,

$$P = 10{,}400 - 2660 \times 2.6 - 2660 \times 8 = -17{,}800 \text{ lbs. per ton;}$$

$$s = \frac{2660 \times 2000}{-17{,}800}(-2.07) = 619 \text{ ft.}$$

This quantity should be plotted with 29 M.P.H. to give one point on the +0.4 per cent retardation curve.

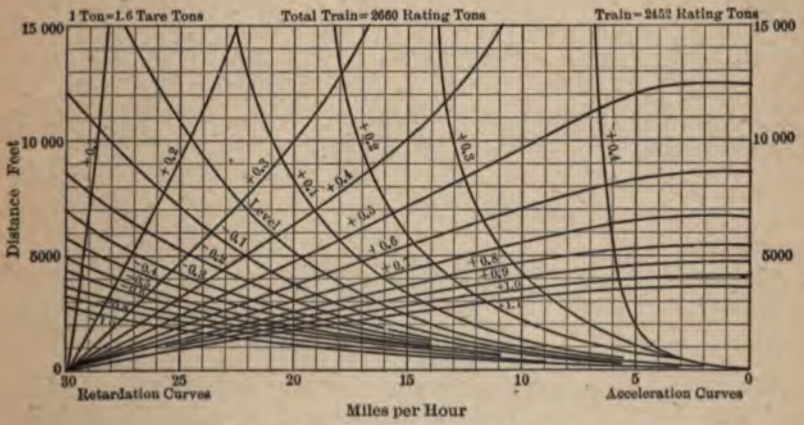

FIG. 35.—Velocity-Distance Curves.

As an illustration of the use of this curve, suppose the consolidation locomotive with full loading for a +0.4 per cent grade makes a start with 5000 ft. of level tangent ahead, followed by 4000 ft. of +0.6 per cent grade, followed by 3000 ft. of −0.2 per cent grade; required to find the speeds at the points of change of grade. On the diagram it is found from the acceleration curve for a level grade that 5000 ft. gives a speed of 20 M.P.H. From the +0.6 retardation curve, it is found that to acquire this speed from 30 M.P.H. would require 3600 ft., and when followed by 4000 ft. more, or a total of 7600 ft., the speed would be reduced to 7½ M.P.H. at the end of this grade. On the −0.2 per cent grade, 7½ M.P.H. is attained in 500 ft., and at the the end of a total of 3500 ft. of a -0.2 per cent grade, the speed is found to be $21\frac{1}{2}$ M.P.H.

While certain refinements such as the greater train resistance below 5 M.P.H are not taken into consideration in this solution, it must be remembered that the entire problem of rating locomotives is not one of extreme refinement, and a solution of this sort will answer the needs in most instances.

Speed-time Curves. In a manner similar to that described in the preceding articles, speed-time curves showing the operation of trains with respect to velocities may be constructed. As previously stated,

$$F=Ma=M\frac{dv}{dt},$$

or,

$$Fdt=Mdv.$$

Integrating between limits of v_0 and v_1, which represents the increment in velocity in an interval of time, t,

$$Ft=M(v_1-v_0).$$

That is, the impulse represented by the product of the force acting on a body and the time through which it acts equals the increment of momentum of the body. The angular momentum of the wheels can be shown to be equal to $\frac{Iv}{r}$, I being moment of inertia of the wheels and r the radius. This quantity is found to be approximately 5 per cent of the momentum of translation of a train, hence, for one ton,

$$Ft=\frac{2000}{32.2}(v_1-v_0)\times 1.05$$

and

$$t=\frac{103}{F}(V_1-V_0) \text{ where velocities are in miles per hour.}$$

As in the preceding article, speed-time curves can be plotted between the time, t, required to make a change in the velocity represented by V_1-V_0, and the speed in miles per hour.

For passenger trains and electric interurban trains, where the hindrance in making time is the chief objection to grades, speed-time curves constructed in this manner offer a ready means of studying the behavior of such trains over any given profile.

Speed-time and distance-time curves can be plotted conveniently from the following equations, which apply to any body acted upon by an unbalanced force and which may be found in most texts on mechanics:

$$F=\frac{Wa}{32.2F}, \quad \text{whence} \quad \frac{1}{a}=\frac{W}{32.2F}, \quad . \; . \; . \; . \; . \quad (1)$$

$$v=at, \quad \text{whence} \quad dt=\frac{1}{a}dv, \quad \text{and} \quad t=\int\frac{1}{a}dv. \quad . \quad (2)$$

$$s=vt, \quad \text{or} \quad s=\int vdt \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

where F is the tractive force in pounds;

W, the weight of the train in pounds;

a, the acceleration in feet per second per second;

s, the distance passed over;

v, the velocity attained in this distance;

t, the interval of time.

As developed by C. O. Mailloux and others, the procedure may be outlined as follows:

1. Curves are plotted showing tractive effort on various grades, and also total resistance curves for the various grades, the difference between these two being the force available for accelerating the train.

2. Reciprocal curves are plotted using speeds as abscissæ and $\frac{1}{a}$ as ordinates. The area under these curves for any interval of speed obviously from equation (2) gives the time in seconds for attaining that change in speed.

3. Speed-time curves are drawn with speeds as ordinates and time of attaining these speeds as abscissæ. The area under these curves, as shown by equation (3), gives the distance passed over.

4. Distance-time curves are plotted with distances passed over as abscissæ and time as ordinates.

5. From the last two curves, a distance-speed curve is drawn with speeds as ordinates and distance as abscissæ. For grades

on which there is an unbalanced tractive force these will be acceleration curves, and on those grades where the total resistance is greater than the tractive force they will be retardation curves, as shown in the previous article.

6. These curves can be applied to any given profile to determine the speed at any point and the time of running to that point.

This process will be made clear by the following example. A Pacific type of locomotive, weighing with its tender 200 tons, draws a train of ten 60-ton steel cars over the profile shown in Fig. 39. Required to plot speed-distance and time-distance charts for this profile. It assumed that the profile is properly compensated for curvature, so that the virtual profile is shown.

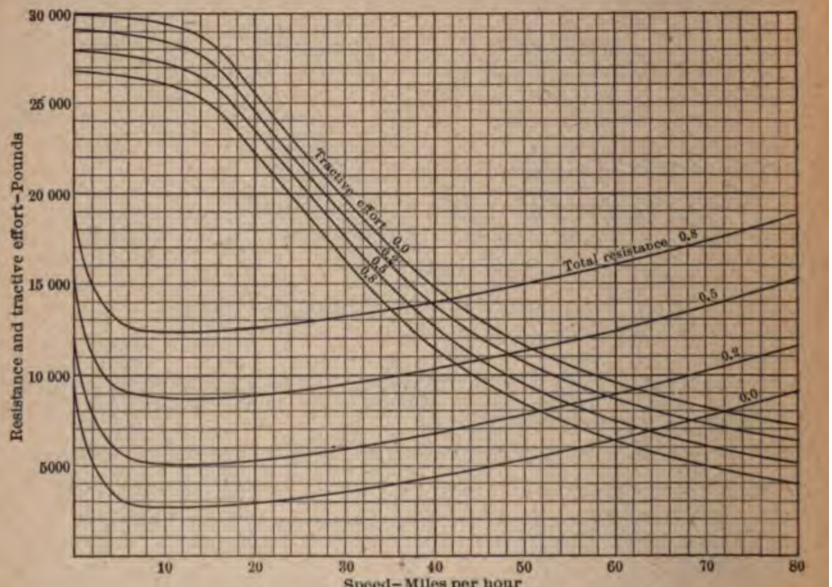

Fig. 36.—Traction and Resistance.

The net tractive effort and total resistance for the different grades encountered are drawn for various speeds in Fig. 36. Reciprocal curve grades are shown in Fig. 37. By finding the area with the aid of a planimeter under these curves at intervals of 15 feet per second, the *speed-time* curves of Fig. 38 (*a*) were plotted. By obtaining the areas under these speed-time curves at one-minute intervals, the *distance-time* curves were drawn as shown in (*b*). By combining the co-ordinates of these two sets of curves, *distance-speed* curves were plotted as in (*c*).

To obtain the final distance-time curve for the case at hand, Fig. 39, the profile is plotted on tracing cloth and superimposed on the distance-time curves described above so that the zero station of the profile falls on the 0.0 point of the curves, and the distance-time curve corresponding to the first grade is traced for the entire length of that grade. Then the tracing cloth is shifted horizontally until the end of the curve just drawn falls over the time-distance curve of the next succeeding grade, and that portion of the distance-time curve is traced, and so on.

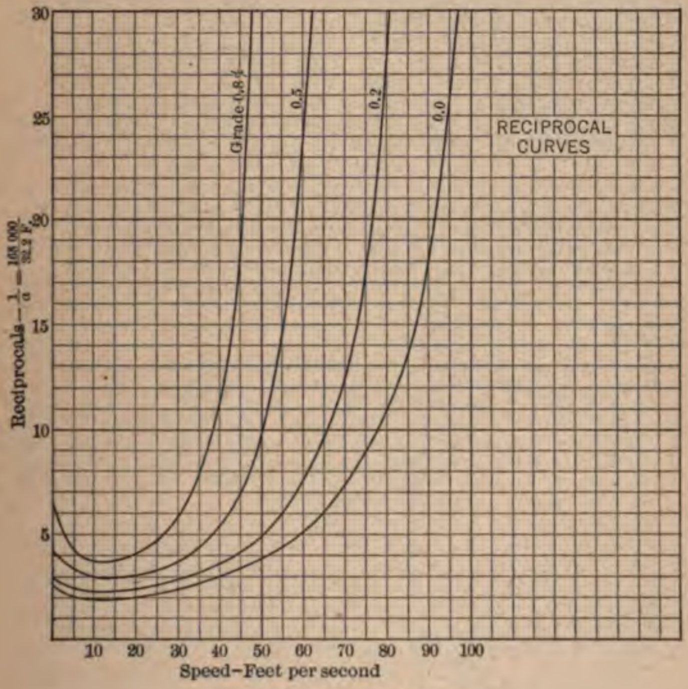

Fig. 37.—Reciprocal Curves.

To apply the profile to the distance-speed curves, Fig. 39, the procedure is similar, except that when the tracing cloth is shifted, it is moved vertically instead of horizontally until the unfinished end of the curve drawn falls on the distance-speed curve corresponding to the succeeding grade. Whenever a grade is reached at a speed that the locomotive cannot maintain on that grade, the speed will decrease to that which can be maintained, provided the grade is long enough for this speed to be attained. The distance required to effect this change in speed may be obtained from equation (3) on p. 192, viz.:

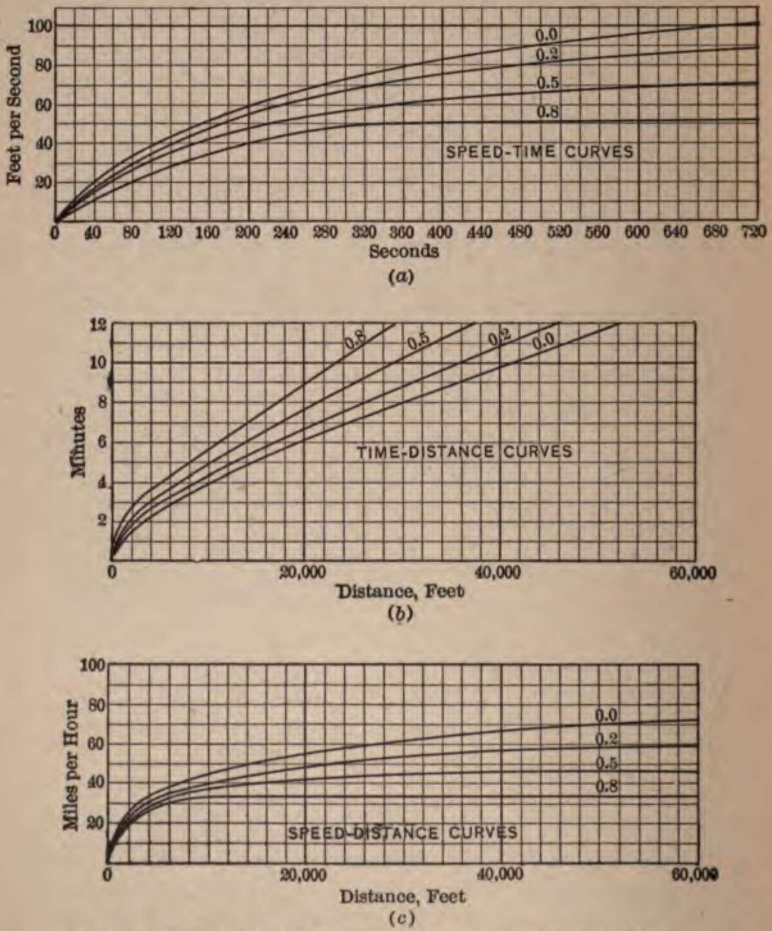

FIG. 38.—Speed-time, Distance-time, and Distance-speed Curves.

$$s=\frac{70.4}{F}(V_2^2-V_1^2),$$

in which F may be taken as the average retarding force per ton for these two speeds, and may be obtained from the difference in the ordinates to the tractive effort and total resistance curves of Fig. 36.

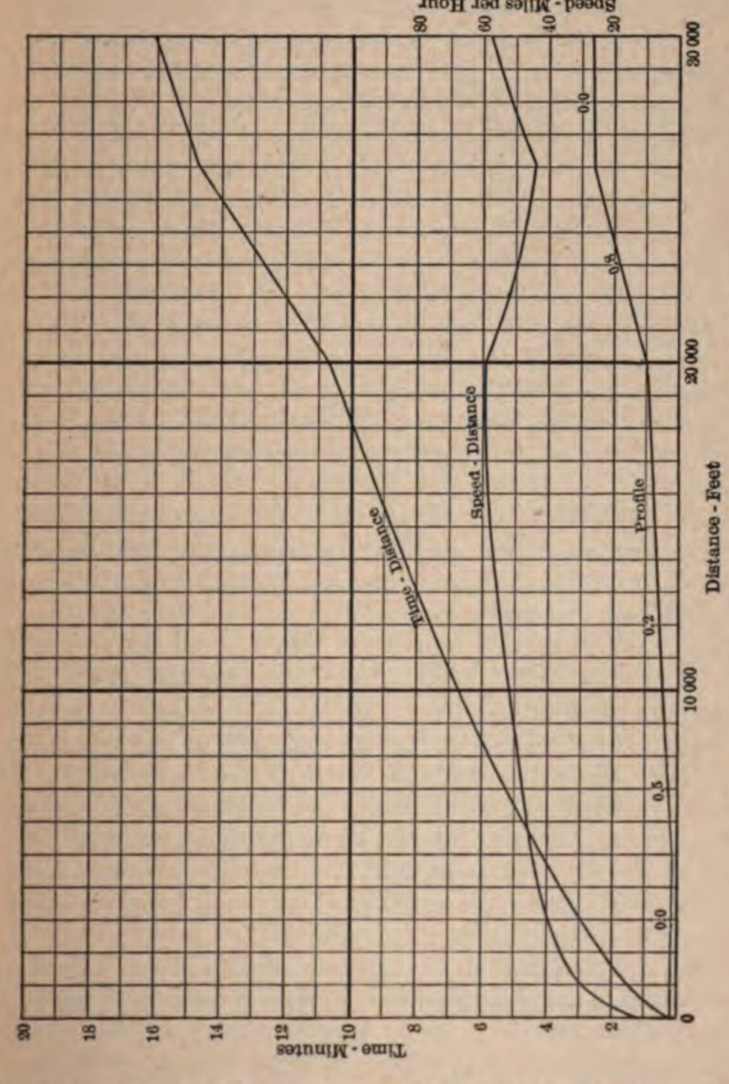

FIG. 39.—Time and Speed Schedule for an Actual Profile.

The resulting chart indicates the time required to reach any point on the profile and the speed obtaining at that point, provided, of course, that the locomotive is rated at its given capacity. Adjustments for applying brakes and for down grades can be made without difficulty.

A lucid exposition of the use of these curves may be found in "Locomotive Operation and Train Control," by Prof. A. J. Wood, published by McGraw-Hill Book Company.

Practical Use of Momentum Grades. While the indiscriminate use of momentum grades in the design of new location is not to be commended, as stated previously, yet in the reconstruction and remodeling of existing lines, and under certain other conditions, their use may prove advantageous. Grades not intended as strictly momentum grades will be operated as such by train crews in many instances. The running time of freight trains, a matter of growing importance because of increased wages and demand for shorter working hours on the part of train crews, may be materially affected by a judicious use of momentum in making time on certain grades. The track should be maintained in such condition as to permit the speed in the sags required by such operation and some changes in the design of rolling stock may be necessary. At any rate, probably the chief benefits to be derived from momentum grades will result from the ability to make better time over the division rather than from any increase in train loading that may be rendered possible. A careful study of the virtual profile, therefore, should be undertaken in connection with the forming of train schedules and the making up of the time-table, even though conservative location design would not allow the use of momentum in the adjustment of grades for the maximum train load. It should be stated, however, that in all schemes for the use of momentum grades, the calculations should be made to provide for stops at all water tanks, stations, block signals, etc., in order to ascertain the performance in the event that such stops are required.

The construction of speed-time, space-time and speed-distance curves renders the calculations concerning momentum operation fairly definite, and train schedules might very well be formulated to realize the advantages of the speed capacity of the locomotive as well as the load capacity. Many railroads have constructed for their own use diagrams showing the performance over their own line by their rolling stock. Besides the paper by

Mr. A. C. Dennis referred to above, the reader will find illuminating discussions on tonnage rating on the basis of momentum diagrams in various engineering publications, among which may be mentioned, Locomotive Tonnage Rating, Southern Pacific Lines, Bulletin No. 1, Am. Ry. Eng. Assn.; Reduction of Grade on Railroads, C. D. Purdon, Journal, Assoc. Eng. Soc. Vol. XXXI; Economics of Revision Work, Union Pacific R. R., by J. B. Berry, Chief Engineer, Proc. Am. Ry. Eng. Assn. Vol. V; Chicago Great Western Momentum Grade Diagrams, *Railroad Gazette*, June 5, 1903.

Rise and Fall. As was explained in the preceding chapter, those grades that have a limiting effect on the weight of train that can be pulled over a division cause a loss in addition to that involved in lifting the train through the ascent, owing to the fact that they compel the engine to pull less than its proper load over those portions of the line where the grade is less than the ruling gradient. The second class of grades are those which do not in any way limit the weight of train hauled, but which do incur a certain loss because of increased work done and because of their effect of operating expenses generally. This class of grades is designated as *rise and fall.* Rise and fall may be defined as the rise from a datum elevation to a summit with the corresponding descent to the same datum elevation. The main effect of rise and fall is in connection with fuel consumed and time lost, although other operating expenses are affected to some extent. Rise and fall is commonly classed with curvature and small additional distance as " Minor Details " because of the fact that they are not controlling factors in railway location. They are, nevertheless, very important. The problem of the effect of rise and fall on operating conditions as well as that of other minor details is not capable of exact solution, yet some solution must be arrived at. It is essential that a method be formulated of determining their effect that will be fairly reliable, easily applied and based on information readily obtainable.

Classes of Rise and Fall. Mr. Wellington grouped rise and fall into three classes as follows:

Class A includes rise and fall so light as never to require the application of brakes nor any variation in the throttle of the locomotive. This class is the least objectionable and its chief effect is to cause a fluctuation in the speed. The increased speed due to down grades constitutes stored energy which can be expended in running on the level or up the next grade. The maximum speed in the sag should not exceed the maximum limit for that division and the minimum at the top should probably not be less than 9 miles per hour, according to the recommendation of the committee of the American Railway Engineering Association. Naturally, all grades that do not exceed the angle or grades of repose of trains at any given speed would never necessitate the application of brakes. The operation of this class of rise and fall is illustrated in Fig. 40. A train approaching the profile shown at a speed of 25 miles per hour would have theoretically the velocities indicated at the different points if the engine exerted only enough drawbar pull to overcome ordinary train resistance. As pointed out at another place, however, this theoretical relationship is modified by the speed characteristics of the locomotive.

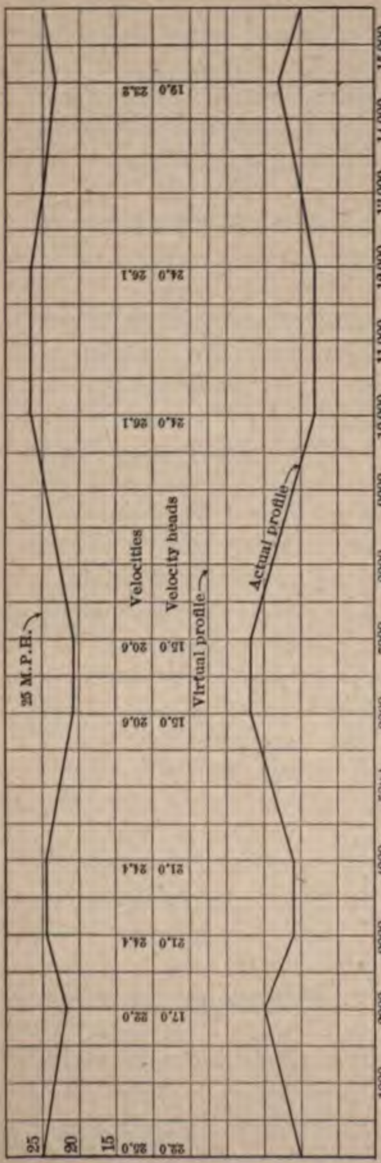

Fig. 40.—Virtual Profile Over Rise and Fall.

Class B includes rise and fall on grades heavy enough to require the shutting off of the steam and perhaps at times the slight use of brakes in descending, but which will not seriously tax the engine in ascending. Whenever brakes are applied, energy is converted into heat and lost so far as the operation of that train is concerned. This class of rise and fall is objectionable because of the liability of trains to break in two at the bottom of a descent when the engineman applies the steam again. A very long Class A grade will come under Class B.

With electric traction, using direct-current motors, braking can be accomplished on such grades by generating current back into the transmission line and thus store a considerable portion of the energy that would otherwise be lost. On certain electrified roads, as high as 50 per cent of the brake energy is thus recovered. Under such conditions, the attendant objections to this class of rise and fall are partly removed.

Class C comprises the rise and fall that occurs as heavy grades, requiring the full power of the engine on ascending, with a frequent use of sand and the likelihood of slipping the drivers, and the vigorous use of brakes in descending. The loss of energy due to the application of brakes is considerable, the wear of brake shoes and tires is serious, and the increased fuel consumption constitutes a large item. Grades that would be Class B for most freight trains usually become Class A for passenger trains and those that would be Class C for freight become Class B for passenger service.

Adverse Grades. An adverse grade may be defined as a grade pitching in the opposite direction from the general slope of the country. Such a grade introduces so much rise and fall without in any way assisting in overcoming the general elevation, and should, therefore, be avoided whenever practicable, or at least, the total of adverse grades should be made a minimum. It is rarely possible to avoid adverse grades entirely, but making the gradient follow the general slope of the country will be a good rule to follow in this connection.

Effect of Rise and Fall on Operating Expenses. As previously stated, the objection to rise and fall lies chiefly in its direct effect upon operating expenses of trains actually run, as distinguished from the effect of ruling grade in limiting the weight of trains and hence determining the number of trains required to carry a given traffic tonnage. Rise and fall does not affect the number of trains operated but does affect the cost of running over the line such trains as are needed. So long as a grade does not limit the weight of train, the cost that it will introduce into operating expenses will be about in proportion to the total rise, or in other words, the cost may be estimated in terms of *one foot rise* as a unit. This statement would be particularly true for any one of the foregoing classes if it were treated by itself. Class A, as has been stated, may be practically dropped from further consideration because of the fact that trains are operated over such grades essentially as on the level, and Classes B and C really constitute the rise and fall under consideration. On this basis, an analysis of operating expenses will be attempted with a view of determining the effect of minor grades on the same.

Maintenance of Way and Structures. The damage done to the roadbed by the increased pull of the locomotive and the application of brakes is offset to an extent by improved drainage. However, the greater shock of wear and tear to increased speeds in sags and the greater tractive effort on up-hill grades cause some increase in maintaining roadbed and track. Only those items considered as being affected will be mentioned below.

Ballast is very slightly affected by grades less than the ruling gradient owing to the fact that improved drainage balances the additional wear due to impact and extra traction. The increase might be 2 per cent for Class C.

Tie expense would be increased somewhat due to the higher speeds on down grades and greater traction on up grades. Probably 5 per cent for Class C, 2 per cent for Class B and none for Class A would be about the proper allowance.

Rail wear is increased also somewhat, especially on Class C grades. Observations indicate that rails wear more on heavy grades than on level tangents. Wellington estimated the wear on rails as increased 10 per cent for Class C for doubling the tractive effort, which would appear to be a reasonable estimate. With traction exerting a shear force equal to one-fourth of the direct pressure of the drivers on the rail, the maximum stress is increased about 5 per cent, by the principle of combined stresses. Under ordinary pulls the shear does not appreciably affect the maximum compressive stress in the rails.

Other track material as well as roadway and track would not be greatly affected, although the labor involved in applying the additional rails, ballast and ties would be something. Perhaps 2 per cent increase would amply cover this item.

Maintenance of Equipment. The increased wear on locomotives because of the heavier pulling and the setting of brakes, as well as on the brake shoes of the locomotive and of the cars, added pull on draft gear, etc., would add somewhat to the maintenance of equipment. Drawheads may be pulled out more frequently, but if vertical curves are properly adjusted to breaks in grade (See Chapter XXIV), very little trouble will arise from this source. Repairs to locomotives and other rolling stock may amount to 1 per cent for Class B grades and 2 per cent for Class C grades.

Traffic Expenses might be affected slightly by the fact that a uniform grade line is a good advertising feature and the frequent application and release of brakes is hard on live stock and is annoying to passengers. However, if this item is affected at all, the influence is slight and it may be neglected, since the total item is not large.

Conducting Transportation. The most serious effect of minor grades arises from the increased cost of transportation. The chief item of increased expense consists of the added fuel required for the locomotive, perhaps 95 per cent of the total effect of rise and fall being attributable to this item alone. The work done in overcoming a given grade represents a certain amount of energy consumed, which must be obtained from the fuel burned. If the thermal and mechanical efficiency of a locomotive were 100 per cent, the supplying of this additional energy would not be so serious, but since the general efficiency is usually only 3 or 4 per cent, the added energy required is a matter of importance. One pound of coal having 11,000 B.t.u. should do $11,000 \times 778 = 8,358,000$ ft.-lbs. of work, but as a matter of fact, it is found to do only 300,000 to 500,000 ft.-lbs., or roughly 5 lbs. of coal will do 1000 ft.-tons of work, or one horsepower hour.

Table XXXIII by Mr. A. K. Shurtleff,* shows the approximate quantity of coal burned per 1000 sq.ft. of grate area of heating surface when the locomotive is not working. Working at full capacity, the locomotive is assumed to burn 4000 lbs. per hour.

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* Proc. Am. Ry. Eng. Assn., Vol. XIV, Part II, p. 6.

TABLE XXXIII

APPROXIMATE POUNDS OF COAL BURNED PER 1000 SQ. FT. HEATING SURFACE. LOCOMOTIVE NOT WORKING

B.t.u. per Lb. Coal.	Firing Up per Trip.	RADIATION, LEAKAGE, ETC., PER HOUR.	
		Standing.	Drifting.
10,000	520	145	263
11,000	515	132	239
12,000	510	121	219
13,000	505	111	202
14,000	500	103	188
15,000	495	97	175

If the additional time spent in working at full and part steam, in standing and in drifting due to rise and fall or any other minor detail can be estimated by the construction of speed-time diagrams or by some other method, the approximate effect on fuel consumption can be estimated with reasonable accuracy. The amount of coal per foot-ton of work done is found to be at times as high as 60 per cent greater on the ruling grade than on minor grades where average speed can be maintained. Fig. 41* indicates the

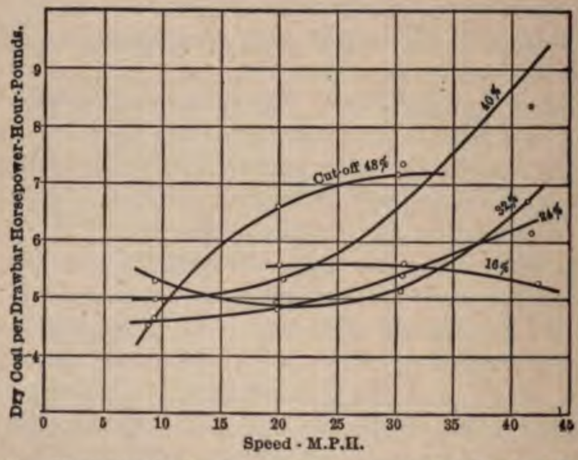

Fig. 41.—Variation in Fuel Consumption with Per Cent of Cut-off.

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* Bull. 82. Eng. Exp. Sta. University of Illinois.

variation in fuel consumption with the per cent of cut-off. The following excerpt from the Report of the Committee on Economics of Railway Location, American Railway Engineering Association, 1915, indicates the variation in fuel consumption on minor grades:

"As the amount of fuel per foot of rise is *greater*, and the amount saved per foot of fall is *less* on ruling than on minor gradients, the variation in fuel consumption for one foot of rise and fall taken together will be much greater than for either element considered separately, and in the case of very light minor gradients, the saving on the one may practically balance the increase on the other.

"The following figures are the result of calculations as to fuel increase and decrease for different gradients, momentum not considered, the train being loaded for 1 per cent ruling grade at a maintained speed of 5 miles per hour, and for 0.3 per cent ruling grade at maintained speed of 7½ miles per hour, with average loading of cars, fuel 11,000 B.t.u., simple engine, and refer to tons of fuel per million gross train-tons (including engine-tons):"

TABLE XXXIV

FUEL CONSUMPTION ON RISE AND FALL

Ruling Grade, Per Cent.	Actual Grade, Per Cent.	Tons of Fuel.		
		Increase, 1 Ft. Rise.	Decrease, 1 Ft. Fall.	Increase, 1 Ft. Rise and Fall.
1.0	1.0	4.34	0.72	3.62
1.0	0.8	3.62	0.90	2.72
1.0	0.6	2.96	1.20	1.76
1.0	0.4	2.40	1.80	0.60
1.0	0.3	2.24	2.04	0.20
1.0	0.2	2.15	2.04	0.11
1.0	0.1	2.15	2.04	0.11
0.3	0.3	4.01	1.93	2.08
0.3	0.2	3.33	1.93	1.40
0.3	0.1	2.69	1.93	0.76

The following data concerning fuel consumption are given by Mr. A. K. Shurtleff for certain test runs over a division consisting of three engine districts, for one week's actual operation:

Total freight locomotive miles....		27,575
Total freight locomotive trips....		220
Heating surface per locomotive...		2,905
Hours delay (standing)..........		855.4
Hours drifting..............	408.2	
Hours working.............	1312.6	
Total hours running time.................		1,720.8

353.

Estimated Fuel Used (11,000 B.t.u.)

	Lbs.
Firing up: 220 trips at 1496 lbs..........	329,120
Standing: 855.4 hrs. at 282.46 lbs.......	328,012
Drifting: 408.2 hrs. at 694.3 lbs.........	283,413
Working: 1312.6 hrs. at 4000 lbs.........	5,250,400
Total estimate.....................	6,190,945

If 6 lbs. per ton may be taken as an average figure for train resistance, each 0.3 per cent grade of rise will add 100 per cent to the resistance for level track. From the above data, it appears that probably about 80 per cent of the total fuel consumed is utilized in hauling the train, hence, the fuel used per train-mile over 0.3 per cent grades will be increased as follows for 15.84 ft. of rise and fall per mile, allowing an additional 5 per cent on Class C for loss of efficiency due to crowding of fires:

Class B, due to added resistance, 80 per cent.

Class C, due to added resistance, 80 per cent; applying brakes, 2 per cent; loss of efficiency, 5 per cent; total, 87 per cent.

In other words, for any stretch of Class B grades the fuel consumption will be increased 80 per cent and for Class C, 87 per cent for each 15.84 ft. rise and fall.

These items of operating expense are collected in Table XXXV. The results indicate that the operating expense per train-mile would be increased 7.74 per cent for Class B and 8.92 per cent for Class C grades for each 15.84 ft. rise and fall, or for 1 ft. rise and fall, 0.48 and 0.56 per cent respectively for Class B and C.

TABLE XXXV

EFFECT OF RISE AND FALL ON OPERATING EXPENSES

0.3 Per Cent Rise, or 15.84 Ft. Rise per Mile

Item.	Average Per Cent, 1914.	Proportion Affected, Per Cent.		Total Cost, Per Cent	
		Class B.	Class C.	Class B.	Class C.
Ballast	0.33	0	2	0	.01
Ties	3.10	2	5	0.06	0.15
Rails	0.88	5	10	0.05	0.09
Other track material	0.99	0	2	0	0.02
Roadway and track	6.85	0	2	0	0.13
Locomotives	9.34	1	2	0.09	0.19
Other rolling stock	12.98	0	1	0	0.13
Fuel, road locomotive	9.42	80	87	7.54	8.20
Total	....	....	....	7.74	8.92

For one train each way per day, with operating expenses at \$1.76 per train-mile, the elimination of 1 ft. of rise and fall of Class C grades would mean a saving annually of \$1.76 × .0056 × 365 × 2 = \$7.20. This, capitalized at 5 per cent, would amount to \$144, or the sum that might justifiably be spent to remove 1 ft. of rise and fall for each average train operated each way per day.

Approximate Solution. It will be observed from the above analysis of operating expenses that the chief effect of rise and fall is the increased fuel consumption. Taking fuel as the only item affected, the Committee on Economics of Railway Location of the American Railway Engineering Association in 1915 calculated the cost of the rise and fall on approximately the basis above outlined for various prices of coal. Table XXXVI taken from this report shows the capitalized values of fuel consumed in overcoming 0.1 ft. of rise and fall per daily train one way per annum. This table is computed on the assumption that 5 lbs. of coal are consumed in producing 1000 foot-tons of work, and for any other assumption the results given in the table should be divided by the ratio between 5 and the figure assumed. Also for any other per cent capitalization, the results shown should be multiplied by the ratio between 5, the rate for this table, and the rate assumed.

TABLE XXXVI

CAPITALIZED VALUES OF 0.1 FT. RISE AND FALL

5 Lbs. Coal = 1000 Ft.-tons. Interest 5 Per Cent

Price per Ton (2000).	WEIGHT OF TRAIN IN TONS.									
	500	1000	1500	2000	2500	3000	3500	4000	4500	5000
$2	1.82	3.65	5.47	7.30	9.12	10.95	12.77	14.60	16.42	18.25
3	2.73	5.47	8.21	10.95	13.68	16.42	19.16	21.90	24.63	27.37
4	3.65	7.30	10.95	14.60	18.25	21.90	25.55	29.20	32.85	36.50
5	4.53	9.12	13.68	18.25	22.81	27.37	31.93	36.50	41.06	45.62
6	5.47	10.95	16.42	21.90	27.37	32.85	38.32	43.80	49.27	54.75
7	6.38	12.77	19.16	25.55	31.93	38.32	44.71	51.10	57.48	63.87
8	7.30	14.60	21.90	29.20	36.50	43.80	51.10	58.40	65.70	73.00
9	8.21	16.42	24.63	32.85	41.06	49.27	57.48	65.70	73.91	82.12
10	9.12	18.25	27.37	36.50	45.62	54.75	63.87	73.00	82.12	91.25

As an example of the use of this table, suppose that a locating engineer finds that the probable traffic will consist of two daily trains (one each way) of 500 tons, two of 1000 tons, and six of 3500 tons; that coal cost $4.50 per ton; interest at 5 per cent.

	Capitalized Cost.
Two 500-ton trains at $4.09	$ 8.18
Two 1000-ton trains at $8.18	16.36
Six 3500-ton trains at $28.79	172.74
Total for 0.1 ft. rise	$197.28

In the case of coal or ore roads where practically all the loaded trains are in one direction and those in the other are empty, the coal consumed would be taken as 4 lbs. and 8 lbs. per 1000 ft.-tons for the loaded and empty trains respectively.

CHAPTER XV

USE OF ASSISTANT ENGINES AND ADJUSTMENT OF GRADES FOR UNBALANCED TRAFFIC

Reducing the Effectual Ruling Gradient. The ruling gradient may not be the maximum gradient in every case, as has been shown. The use of momentum to assist in overcoming short steep grades may be used to advantage in certain cases, as was seen. Two other devices may be used under certain circumstances to accomplish the same result, viz.: (1) utilizing helper engines over a short stretch of the line, where it is impracticable to reduce the grades to the ruling gradient obtaining over the remainder of the division, and (2) balancing the grades for unequal traffic so that the heavier flow of traffic will be opposed by the lighter grades. In almost every instance of location, most of the grades are much less than the ruling gradient, the conditions of the latter applying to only two or three grades on the division. It is manifestly desirable to reduce these few heavy grades until the rate of ruling gradient occurs so frequently over the division that it is uneconomical to make further reduction. Sometimes this reduction is made in the actual gradient by making further excavation, and sometimes it is effectually made by one of the two devices above mentioned, particularly the first. How this is accomplished will be briefly outlined in the present chapter.

Conditions Favoring the Use of Assistant Engines. That a railroad location might be designed with a low ruling gradient over most of the line with steep gradients bunched over a comparatively short stretch and provision made for operating this short stretch by means of assistant engines was early recognized. The principles underlying the use of such engines was first explained by Gen. Herman Haupt * in 1873. At the present time, the practical economy secured by the application of this idea is well understood and is utilized by nearly all roads which traverse mountainous regions. A location which is for the most part situated on the plains or prairies and can follow the easy natural slopes of the valleys and the ridges, but which for a comparatively short portion of its length must pass over mountains or steep hills, so that a low grade cannot be obtained through such region except at an enormous cost and involving a long detour, is best adapted to utilizing the advantages of helper grades. For example, the A., T. & S. F. R. R. has a ruling gradient of about 0.6 per cent from Chicago to the western mountains, where the ruling gradient is increased to about 2.0 per cent; the D., L. & W. R. R. has a ruling gradient of about 0.6 per cent except where it passes over the Blue Mountains, at which point it is about 1.5 per cent; The C., M. & St. P., the Gt. Northern, Union Pacific and the Northern Pacific railroads have similar conditions with which to contend. Wherever a comparatively short stretch of rough country must be crossed, the possibility of using assistant engines should be considered.

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* *Railroad Gazette*, July 5, 1873.

Economy of Helper Grades. As Wellington so aptly stated, "The secret of the vast economies which may often be realized by the skillful use of assistant engines is this—that as respects construction, we work with Nature instead of against her, and as respects operation, we gain a like advantage by keeping every engine while running fully at work, the greater portion of the hard work in foot-pounds being done on a small portion of the division, with such favorable through grades, in many instances, that there is little more need for an engine on the remainder of it than to keep the longest trains moving and under control." As shown in Chapter XIII, the loss due to a high ruling gradient is not so much the cost of work actually done by the locomotives in hauling a train up the gradient as it is to the work that they do *not* do while pulling their trains with little exertion over the stretches of easy grades between. The actual cost of doing the work is not so great if it can be done directly without any unnecessary loss or application of power. By adopting low grades where natural slopes favor low grades and using steeper grades with assistant engine service over the summits, not only the cheapest line is obtained, but the lowest effective through grade is secured at the same time with its resulting reduction in cost of operation.

Moreover, not every train that passes over a division can be given its maximum tonnage rating, consequently pushers are not needed for the lighter trains, and the only loss from operating such trains is that which results from the ruling grades as so much rise and fall. Where traffic is heavy, several pushers are stationed at the helper grades, and if they can be kept busy all the time, the cost of pusher service is reduced to a minimum, but where the traffic is light and the helper engines have long waits between runs, the service is costly. Where the pusher grades are near a terminal, the yard engine may be able to render pusher service at times, and, on the other hand, pusher engines may be given yard work during idle time.

Method of Operation. For freight service, the assistant engine is always a pusher, for in this manner of operation the helper engine can be attached and uncoupled without stopping the trains. On passenger trains, however, state laws in some instances forbid the use of " pushers," consequently the assistant engine is attached ahead of the regular road engine as a " puller." This arrangement necessitates stopping the train to allow the coupling and uncoupling of the helper, or at least, the slowing down of the train to allow time for the helper to run ahead and take a siding. This procedure is followed especially by roads crossing the eastern mountains, while the roads which traverse the Rocky Mountains generally attach the assistant engine at the rear when more convenient. However, in the latter case, the two engines are commonly operated as a double header on account of the length of the grades, occupying as they do practically the entire division.

Balancing of Through and Pusher Grades. Obviously the entire net tractive effort of the assistant engine is utilized in overcoming the resistance due to grade, inasmuch as adding this locomotive adds nothing to the train resistance. Pusher grades should be so adjusted as to rate of ascent that the road engine together with the helper engine or engines will pull the maximum train up the pusher grade with the same degree of facility as the lone engine on the through ruling gradient. If the two engines are of equal power, the load for each is one-half of what it would be for one, or one-third in the case of two helpers. If the helper can exert more power than the road engine, then the load is unequally divided. Thus, if the helper can exert 10 per cent more power than the road engine, which is perhaps a reasonable assumption, since the former is not subject to the long-maintained effort of the latter, the power is divided $\frac{1}{(1+1.10)}=47.6$ per cent to the road engine, leaving 52.4 per cent to the helper. The grade on which the road engine can haul its portion of the load will be, therefore, the proper gradient for pusher service.

To derive a general formula for equating through and pusher grades, let

P = drawbar pull of the road locomotive in pounds;
P' = drawbar pull of the pusher locomotive in pounds;
W = weight of road locomotive in tons;
W' = weight of pusher locomotive in tons;
C = the number of cars in the train;
G = the ruling gradient in per cent;
G' = the corresponding pusher grade in per cent;
T = the total weight of train in tons.

Assuming the total train resistance is given by the formula $R=2.2T+122C$, then for a single engine on a G' grade,

$$P-20G'W=(20G'+2.2)T+122C,$$ and for both engines,

$$P-20G'W+P'-20G'W'=(20G'+2.2)T+122C,$$ from which,

$$G'=\frac{P+P'-2.2T-122C}{20(T+W+W')},$$ or in general,

$$G'=\frac{\Sigma P-2.2T-122C}{20(T+\Sigma W)}.$$

Assuming that the helper can do 10 per cent more than the road engine because of the short duration of its effort, this relationship obtains:

$$2.1(20GT+2.2T+122C+20GW)=20G'(W+W')+20G'T+2.2T+122C$$

and

$$G'=\frac{2.1(T+W)}{W+W'+T}G+\frac{0.111T+6.7C}{W+W'+T}.$$

For $W=W'=200$ tons, $T=2000$ tons, $C=50$ cars, $G=0.5$ per cent,

$$G'=\frac{2.1(2200)}{2400}\times 0.5+\frac{222+335}{2400}=1.20.$$

In a similar manner, but assuming the tractive effort the same for the two engines, Table XXXVII was prepared for average conditions by Mr. R. N. Begien, Chief Engineer, Baltimore and Ohio R. R * In the past, many calculations using a high train resistance have fixed the pusher grades at higher rates than the above equation will give and higher than those in the table, and as a result the *pusher grades have become the limiting grades.*

TABLE XXXVII

BALANCED GRADES FOR ASSISTANT ENGINES

Road Engine Grades.	Helper Engine Grades.		
	1 Helper.	2 Helpers.	3 Helpers.
Level	0.204	0.400	0.587
0.05	0.302	0.536	0.766
0.10	0.401	0.673	0.946
0.15	0.497	0.813	1.114
0.20	0.594	0.954	1.283
0.25	0.688	1.083	1.441
0.30	0.782	1.212	1.599
0.35	0.874	1.336	1.749
0.40	0.966	1.461	1.899
0.45	1.055	1.580	2.039
0.50	1.145	1.699	2.179
0.55	1.233	1.813	2.311
0.60	1.321	1.928	2.444
0.65	1.407	2.037	2.569
0.70	1.494	2.147	2.695
0.75	1.578	2.253	2.814
0.80	1.662	2.359	2.933
0.85	1.744	2.460	3.045
0.90	1.826	2.561	3.158
0.95	1.907	2.659	3.271
1.00	1.988	2.757	3.384

Whether one or more pusher engines will be used will determine the choice of grades. Where the through ruling gradient for the road engine is 0.5 per cent, any grade between 0.5 and 1.145 per cent should be reduced to 0.5, or else it will have to be operated with a pusher, and grades between 1.145 and 1.699 per cent should be reduced to 1.145, or it will have to be operated with two helpers, etc. Obviously, these intermediate grades are not economical, for either they do not permit the maximum rating over the other grades with one engine or they do not use the full power of the helper. Intermediate grades would, therefore, come under the category of rise and fall for two engines and of a ruling grade for one, and any grade reduction should be made accordingly.

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* Proc. Am. Ry. Eng. Assn., Vol. XII.

Assistant Engines in Passenger Service. Usually passenger trains are not loaded with the maximum tonnage that they can pull over the division, but rather with a tonnage that will allow them to make a desired speed over the division. By reference to Fig. 11 it is obvious that a locomotive is capable of pulling a larger load at low speed than at high, hence the advisability of using assistant engines in passenger service will be a question of the value of speed rather than of hauling the maximum tonnage. Under competitive conditions, speed may have great value and may determine whether the road will receive a due proportion of the passenger business.

Table XXXVIII, taken from Wellington's Economic Theory of Railway Location, shows the loss of time per mile in minutes by a decrease in speed from the given higher speed to the given lower speed to which the velocity is reduced. Thus if the speed were reduced from 50 to 40 M.P.H., one-third of a minute would be lost every mile that the train travels at the reduced speed. It will be observed from this table that a decrease in speed at the

TABLE XXXVIII

LOSS OF TIME IN MINUTES PER MILE DUE TO A DECREASE OF SPEED OF TRAINS

LOWER SPEED	HIGHER SPEEDS, MILES PER HOUR.									
M.P.H.	15	20	25	30	35	40	45	50	55	60
10	2.0	3.0	3.6	4.0	4.29	4.5	4.67	4.83	4.91	5.0
15	....	1.0	1.6	2.0	2.29	2.5	2.67	2.83	2.91	3.0
20	....	....	0.6	1.0	1.29	1.5	1.67	1.83	1.91	2.0
25	....	....	....	0.4	0.69	0.9	1.07	1.23	1.31	1.4
30	....	....	....	....	0.29	0.5	0.67	0.83	0.91	1.0
35	....	....	....	....	....	0.2	0.38	0.54	0.62	0.71
40	....	....	....	....	....	....	0.17	0.33	0.41	0.5
45	....	....	....	....	....	....	....	0.16	0.24	0.33
50	....	....	....	....	....	....	....	...	0.08	0.17
55	....	....	....	....	....	....	....	...	...	0.09

higher velocities causes a less loss of time than the same decrease at lower velocities, while the percentage of gain in tractive power is greater, a fact that should be taken into consideration in studies involving passenger service. For this reason, only limited trains probably will find it economical to use helper engines. The economies resulting from the use of helper engine grades should be calculated separately for freight and passenger service owing to the difference in the governing conditions as outlined above.

Duty of Assistant Engines. The mileage that assistant engines may accomplish will vary with the amount and character of the traffic and with its distribution. While a pusher might be counted on to run 100 or even 130 miles per day under most favorable circumstances, such ideal conditions do not usually exist. A pusher must be ready for service at any time, and it would rarely happen that the traffic and the train schedule could be so adjusted that a train would be arriving at the foot of the grade at the exact time that the pusher is returning. Consequently, idle periods result. Moreover, if the demand is just a little more than can be taken care of by n engines, $n+1$ engines must be used with a decreased chance of performing the maximum mileage. As stated in a previous paragraph, if the bottom of the pusher grade is near a terminal, pusher engines may be used for yard service in the terminal during idle intervals and yard engines may perform pusher service at times of congested traffic, although switch engines with small drivers and no pony truck are not well adapted to pusher service.

Where two pusher grades are not more than five or six miles apart, they can usually be operated as one pusher grade more economically than as two. However, this will depend upon the density of the traffic, and in every case the cost of running this extra mileage should be balanced against the cost of maintaining the extra engine and the necessary switching facilities at the second grade. If several engines have to be used on the two grades to take care of the traffic, for freight service at any rate, it will probably be economical to divide them between the two grades. This will necessitate installing and maintaining an extra switch with its accessories, which may be a comparatively large item, especially if signals are installed at the switches. Moreover, the cost of stopping the train for coupling and uncoupling should be taken into consideration. Pushers operate most effectively on double-track roads which are equipped with block signals, for under these conditions the assistant engines can run down the grades without special dispatching, subject only to the observance of signals.

Cost of Assistant Engine Service. The operation of assistant engines is so different from that of road engines that to assume the cost of pusher service to be about the same per engine-mile as for road engines is radically incorrect. The proper method of procedure is to consider a certain number of engines being assigned to this work on which the fixed charges will be a calculable amount and then to add the appropriate amount for the actual mileage run. The total cost may be analyzed as follows:

1. The fixed charges will include interest on the initial investment and depreciation on the locomotives used, also interest and depreciation charges on the sidings, signals and other track structures which the service necessitates.

2. The operating costs will include:
    a. Maintenance of way and structures, such as signals, switches, etc., that are charges directly to this service.
    b. Repairs to locomotives used.
    c. Wages of enginemen.
    d. Fuel for pusher locomotives.

The fixed charges will depend, of course, on the character of engines used for pusher service. Inferior equipment is very commonly employed as pushers, although some roads have built heavy locomotives, even of the Mallet type, for pusher service over steep grades.

The proportion of maintenance of way and structures expense that is chargeable to pushers is very difficult to determine. In the first place, very little information exists concerning the relative destructiveness of a locomotive and its train. The expenditure for track maintenance due to the pusher ascending the hill would doubtless be as great as for the road engine, and perhaps half as much again on descending. Working out the solution on the basis of the total mileage will probably be not far wrong, because half of the mileage will necessarily be under heavy working conditions with respect to tractive effort, and on the whole the total will represent nearly average engine mileage.

The remaining items of operating expense will be about the same therefore as for normal engine mileage. Table XXXIX represents a fair estimate of the cost of pusher engine mileage in terms of the cost per train-mile.

TABLE XXXIX

COST OF PUSHER SERVICE PER MILE

Item.	Average Cost, 1910, Per Cent.	Proportion Affected for Pusher.	Cost per Pusher Engine-mile. Per Cent.
Track expenses	13.2	50	6.6
Bridges, etc.	1.7	50	.8
Crossings	.4	50	.2
Signals	.3	50	.1
Supt. of equipment	.6	20	.1
Steam locomotives	8.6	100	8.6
Road enginemen	6.1	100	6.1
Enginehouse, road	1.7	50	.9
Fuel for road locomotive	10.4	100	10.4
Water and other supplies	1.1	100	1.1
Interlockers and signals	.5	20	.1
			35.0

Thus, if the cost of operation per train-mile is \$1.50, the cost per pusher engine-mile will be \$1.50×.35=\$0.52.

Adjustment of Grades for Unbalanced Traffic. From the nature of railroad operation, the same number of trains will be run in one direction in a given period of time, say a year, as in the other. While a few freight cars may be returned by other routes, essentially the same number of cars will go in both directions, and obviously the same number of locomotives will have to be run. If, therefore, the movement of traffic is materially heavier in one direction than in the other, the grades opposed to the lighter returning traffic may be made heavier than those opposed to the main flow of traffic by an amount that will make the total resistance over the ruling gradient in one direction equal to the total resistance in the other. No advantage is secured by reducing the return grades lower than this, other than that which might arise in the case of abnormal flow of business in the other direction and that which is secured from the elimination of rise and fall generally. On most of the locations that have been made within the past two decades, this condition of unbalanced traffic has been given consideration and appreciable economies have been effected thereby.

1 **Conditions that Give Rise to Unbalanced Traffic.** The relative location of natural resources, cities, rural communities, industries, etc., give rise chiefly to the conditions of unbalanced traffic. Some of the more common cases which cause unequal traffic may be mentioned.

1. The natural tendency of farm products to go to the large cities, and especially to the export cities.
2. Lumber and other forest products naturally go from forest areas toward the centers of population.
3. Coal roads carry coal from mines to cities or to a main line and usually there is no commensurate return traffic.
4. Roads that carry iron or other ore from mines to the mills or smelters seldom have a return business that will equal the traffic derived from this source.
5. Mine spur tracks naturally have loads in one direction only.
6. Industrial spur tracks and logging railroads likewise are necessarily designed for business in one direction only.

Traffic Characteristics. From a study of the conditions attending unbalanced traffic, the following observations seem to be warranted:

1. The number of locomotives will necessarily be the same in both directions, and even though an engine hauls a full load in one direction and a light one in the other, the cost of operation of the locomotive will be essentially the same in both directions.
2. The number of freight cars will be practically the same in both directions ultimately, even though they are returned largely as empties, and even though some cars are returned over other routes. If a smaller number travel in the direction of the light traffic owing to the fact that some cars may be scrapped at the terminus toward which the traffic tends and others may be leased to other railroads at the same point, such conditions tend to make a still greater disparity in the flow of traffic.
3. The number of passenger cars and trains will necessarily be the same in both directions, and since the live load, or revenue load, is small in comparison with the tare load of the weight of the cars, it will make small difference whether the passenger

travel is balanced or not, and the passenger business may be considered as balanced in the two directions. As a matter of fact, since almost every journey involves a going and a return, passenger traffic will ultimately be about equal in amount, although it may be periodic in its movement. This statement does not apply to roads carrying large numbers of immigrants.

4. One of the most common sources of unbalanced traffic is the fact that heavy bulky freight, such as grain, lumber, coal, etc., is bound toward the cities, while light manufactured products, such as machinery, furniture, etc., travel in the opposite direction. The fact that the latter pays a higher tariff rate compensates in part for the decreased tonnage, so far as revenue is concerned, and makes the saving of cheaper construction resulting from higher grades all the more advantageous.

5. Too much weight should not be given to the possibility of unbalanced traffic in the design of a new location, because a shifting of industrial conditions, such as the exhaustion of mineral or forest resources, or the new development of others, may alter the flow of traffic so as to equalize, or in some cases even reverse the direction of heavy tonnage.

6. The engine division should be taken as the unit over which the flow of traffic is considered, because the effect of local conditions along the line may be such as to alter the general conditions existing over the entire road.

7. A mixed traffic is much less likely to be extremely unbalanced than is traffic consisting of a preponderating single commodity, such as coal, ore, grain, lumber, live stock, etc.

Determination of the Proper Balance of Grades. Where the traffic is permanently heavier in one direction than in the other on existing lines, when contemplating a revision of the location, or where an unbalanced traffic may certainly be predicted in a new location, the grades should be adjusted to the traffic in either direction. In making such calculations it should be kept in mind that the train resistance per ton is higher for empty or lightly loaded cars than for fully loaded ones. The percentage of pay-load of the total load in the direction of heavy traffic averages about 60 per cent for box and flat cars and about 75 per cent for mineral cars. If on a road hauling general commodities the traffic is twice as heavy in one direction as in the other, the average car would be $.40+\frac{.60}{2}=.70$ as heavy in the direction of light traffic as in the other. By reference to Fig. 26, it is observed that the rolling resistance is about 35 per cent greater for this lighter load, or the total rolling resistance is decreased only about 5 or 6 per cent.

For the determination of the proper balance of grades, the weight and character of the traffic in both directions must be known. If the trains are assumed to return containing the same number of cars as hauled in the direction of heavy traffic, the following general solution of the relation between the grades might be used to illustrate the nature of the problem:

Let W be the weight of a locomotive in tons;
T the total tonnage of a train in the direction of heavy traffic;
G the per cent ruling gradient in direction of heavy traffic;
G' the per cent ruling gradient in opposite direction;
n the ratio of tare to total load in direction of light traffic;
m the ratio of light tonnage to heavy tonnage.

$$20\{W+nT+m(1-n)T\}G'+2.2nT+2.2m(1-n)T+122C$$
$$=20(W+T)G+2.2T+122C$$

from which

$$G'=\frac{W+T}{W+nT+mT-mnT}G+\frac{0.11T(1-n-m+mn)}{W+nT+mT-mnT}.$$

When $m=1$, or the cars return fully loaded, $G'=G$, as it should. Fig. 42 shows the proper balance of grades for average conditions.

Effect of Character of Traffic. On many railroads, the direction of the heavier traffic varies with the season. Coal is shipped to the large cities chiefly in the late summer; fruit is handled naturally in its season; grain is loaded for the most part in the fall and early winter, and other examples will readily come to mind. At other times of the year the flow of traffic may be reversed, but such seasonal fluctuations arising from the character of the traffic handled should not be allowed to influence unduly the general solution of the problem.

It may happen that in certain instances, the character of the commodities may cause speed to be counted in the direction of light traffic as an incentive to reduce the grade to the same rate as the heavy tonnage requires in the other direction. Where dressed meats, live stock, fruit and other perishable commodities constitute the return business in the light direction, it may be desirable to load the trains so that they can make faster time, and consequently the grades will need to be reduced for the light traffic. For a practically exclusive mineral or coal traffic, the expediency of adjusting the grades for the full difference in weight of traffic will hardly be questioned, but it will rarely happen that conditions will justify a marked difference in the gradients in the two directions.

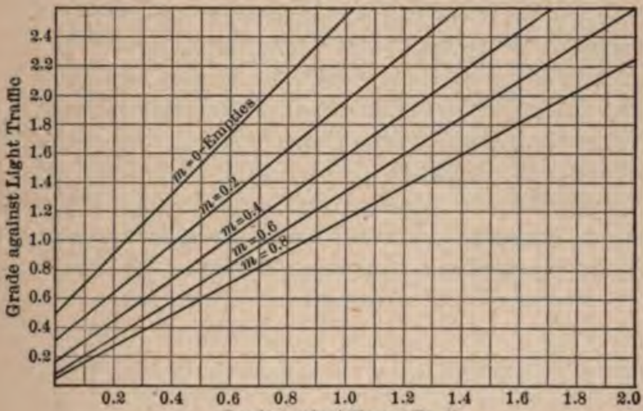

Fig. 42.—Balance of Grades for Unequal Traffic.

Light traffic railways are particularly subject to the conditions of unbalanced traffic, and economies may frequently be effected in the location of such roads by the application of the principles above outlined.

The exercise of some ingenuity on the part of operating and traffic officers may overcome the conditions of a naturally uni-directional traffic. The general movement of commodities and the needs of different communities should be carefully studied with this object in mind. The case of the Great Northern Railroad developing a trade in Japan and China in order to give a westward traffic is an illustration of this point. When this road was first constructed, shipping lumber to Chicago and other lake ports constituted the bulk of its business, and the traffic officers were eager to secure westbound traffic to take back instead of the empty cars. It was at a time when Japan was building railroads to a great extent. The companies over there were paying $29.00 a ton in Antwerp and Brussels for rails delivered in Japan. The Northern Pacific traffic managers secured a price at Chicago of $19.50 per ton, charged $8.00 per ton for freight to Japan, and were able to lay the rails down in that country about $1.50 cheaper than the European price. Needless to state that the westbound cars were occupied thereafter in hauling rails to the west coast. In a similar manner this road and the Northern Pacific created a market in Japan and China for American cotton, and bringing it north to Chicago and Minneapolis, these roads carried it to the west coast for ocean shipment. These roads were also responsible very largely for the creation and stimulation of the oriental market for American flour and many other products as a result of their strenuous efforts to secure a westbound traffic.

CHAPTER XVI

DISTANCE

Relative Importance of Minor Details. Distance is commonly classed with rise and fall and curvature as a minor detail in railway location, and in a very real sense these matters are of secondary importance. The two objectives to be kept in mind in a railway location are:

1. To secure the greatest amount of business possible, and
2. To conduct this business at the lowest possible unit cost.

Anything that does not affect either of these two primary objectives in a controlling manner may be considered as of minor consequence. A railroad is in reality an industrial manufacturing plant, the commodity which it manufactures being transportation, and like all manufacturing concerns, its primary object is to dispose of as much of its product as possible in order to operate the plant at its full capacity, and hence, at its maximum efficiency and economy. Just what is the limiting capacity of a single-track or of a double-track railroad will be discussed in a subsequent chapter, but it may be stated here that a railway with a given equipment represents a certain capacity for conducting transportation, and the more nearly that capacity is utilized, the greater will be the net revenues. A train at a station is a standing offer to sell transportation at the stipulated price, the amount for sale being the capacity of the train. The cost of running the train is largely independent of the load carried, consequently the more nearly the entire stock of transportation can be closed out, the greater will be the profits. This is especially true with a passenger train, for all that remains unsold is lost. If rise and fall, distance, and curvature affect this business so that the road does not operate at its maximum efficiency, they become very important, but generally they do not so affect it, although in some instances they may. By analogy, a company may build a plant to manufacture a given commodity, but if its failure to install a certain device increases the cost of production directly or indirectly, or if the failure to paint its buildings an attractive color keeps business away, then these otherwise minor details become important. Likewise, if the adverse advertising effects of rise and fall, distance, and curvature are such as to cause some traffic to go to competing roads, or to cause serious loss in any other manner, they become very important, for, as has been pointed out, the margin between total revenues and total operating expenses is not great at best, and any arrangement that will increase this margin is worthy of careful consideration.

Distance as a Basis of Rates. As discussed in Chapter VII, the present system of rates existing in America is to a great degree arbitrary and illogical, but the original consideration that was largely used as a basis for fixing rates was distance, and in general rates are approximately in proportion to the distance that the commodity is hauled. Rates are fixed approximately according to distance, not because the cost of transportation is proportional to the distance, but because distance represents a measure of the service rendered that may be comprehended by the lay mind. Moreover, it has been the custom for railroads to charge " what the traffic will bear," hence they have arranged the tariffs with a view to ease of collection as well as to the cost of transportation. Passenger fares are strictly according to distance under non-competitive conditions, and approximately so under competitive.

The value of transportation to the patron, either of freight or passenger, is not only dependent upon the usefulness of the transportation, but is directly connected with the cost of transportation by other means, such as by horses, water, or automobile. The less the fixed charges involved in the method of transportation, the more nearly will the cost vary in proportion to the distance, hence, since the cost of transportation by other methods, e.g., by teams or by auto trucks, which compete in a remote way with railway transportation, is approximately in proportion to the distance, the value of transportation to the patron is dependent to a degree upon the distance.

In regard to the relation between distance and cost of transportation, Mr. Charles Whiting Baker, in analyzing terminal costs, makes* some surprising statements in this connection, which may be somewhat exaggerated but are, nevertheless, very illuminating. He says that the cost of terminal handling is so great in proportion to the cost of actual haulage that, " The total cost of moving freight from its origin in one city to its destination in another is the same for all distances less than 100 miles. . . . The cost of terminal handling in cities is so great compared with the cost of moving a train or vessel when loaded and started on its journey, that the latter may be ignored."

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* *Engineering News*, Vol. CLIII, p. 253.

In the specific case of handling freight between New York and Philadelphia, a distance of 90 miles, the figures are (estimated):

	Per Ton.
Terminal charges at New York	$2.25
Terminal charges at Philadelphia	1.40
Total	$3.65
Cost of hauling at 0.3 cent per ton-mile	.277

or about one-fifteenth of the total transportation charge.

Between New York and Chicago, the terminal charge	$3.65
Haulage 1000 miles at 0.3 cent	3.00

On the basis of the above figures, instead of making freight rates strictly proportional to the distance, they could be more logically and justly made by charging a fixed amount to cover terminal costs that would be independent of the distance to be hauled, and then add an amount per ton-mile (except as affected by competition) to cover the cost of haulage.

However illogical the method of charging rates according to distances, the fact that rates are so arranged at the present time and will probably continue thus for some time at least, should be kept in mind. Distance is an item that is easily comprehended by everyone and is applicable to all roads, and the cost of transportation as well as the value to the patron of the service depend to some extent or in a general way upon distance. Due to these facts as well as to the simplicity of the scheme, distance is quite generally taken as a basis of rates.

Effect of Distance on Gross Receipts. Whether a certain amount of distance inserted in the line or removed from the length of the line will have any effect on the gross receipts will depend upon circumstances and the nature of the traffic carried. The effect on receipts for freight and passenger traffic will differ and these classes of traffic should be considered separately.

For the purpose of discussion, and following a commonly accepted classification, traffic may be divided as follows: .

1. Non-competitive:
    - *a*. Home traffic.
    - *b*. Exchange traffic.
2. Competitive:
    - *a*. Home traffic.
    - *b*. Exchange traffic.

Non-competitive home or local traffic includes that which is handled entirely by the one line and has no choice of route. This class, consisting chiefly of what is known as " way freight," constitutes a considerable portion of the total business of most lines, usually more than 50 per cent of the total. The rate for hauling this class of traffic is in proportion to the distance hauled, hence, additional length of line interpolated between the origin and destination merely serves to increase the total revenue derived therefrom (without proportionally increasing the cost of haulage, as will be seen later).

In the case of non-competitive exchange traffic, the custom as well as the legislative requirement is to form a through rate equal to the sum of the established local rates, and the revenues from such transportation are divided between the carriers participating in proportion to the distance hauled by each, or according to the local rates. Consequently, where these local rates are in proportion to the distance, no loss results from the added distance, and indeed, an actual gain may result, since the cost of transportation is not in proportion to the added revenue.

Competitive home traffic comprises that hauled where two or more routes are offered between the shipping points and the rate between these points is fixed. In this case, the railroad will have to meet the tariff rate regardless of the distance over which it may carry the freight, and for this reason any additional distance that may be inserted in the line will represent a loss equal to the increased operating expenses without any compensating gains. On steam roads, this class of traffic is not very large but tends to increase with the multiplication of railroads, and especially with the development of electric interurban lines serving the same traffic points as the steam lines. On steam roads between large terminals, it may constitute a considerable portion of the total business.

Competitive exchange traffic comprehends that business that is conducted between two points between which the rate is a definite one fixed by competition. Any added distance will cause a loss, but frequently that loss does not fall on the road having the additional mileage. Revenue from any particular shipment over two or more lines is divided among the roads participating in a proportion that is fixed by agreement. If these roads are equally strong and influential, the agreement usually amounts to dividing the revenues according to the mileage that each hauls the shipment, but if one is a minor road and has no other outlet for its traffic because of inability to connect with other lines, then the division is arbitrary and may be entirely disproportionate to the distance hauled, the more powerful road dictating the terms of the contract. Frequently, also, an arbitrary deduction is made to cover terminal charges and other costs of handling that are incurred by one or more of the roads participating which entitle them to a larger share of the revenue. It also happens sometimes that a road that is sufficiently powerful can enforce "constructive mileage" on the basis of an old route where the length of line has been diminished by a cut-off. As stated in Chapter VII, it is customary for the road receiving the freight to pay the charges of the road delivering the same to the destination.

However, in those cases where the revenue is divided according to the distances hauled, additional length of line may not be a disadvantage at all, but may serve, on the other hand, to enhance the fraction of the joint revenue coming to the home road. For example, if the home road furnished 50 miles of a shipment and the foreign road 200 miles, then the home road will receive $\frac{50}{(200+50)}$ or 20 per cent of the receipts from the shipment. If the home road is made five miles longer, it will receive $\frac{55}{(200+55)}$ or 21.5 per cent of the revenue, and inasmuch as this added revenue is greater than the added cost of handling over the extra distance, such an increase in distance in this case would be an advantage. Reversing the conditions, however, and assuming the five miles added to the 200-mile line, and the latter would receive $\frac{205}{255}$ or 80.6 per cent of the proceeds instead of 80 per cent in the first instance. The additional 0.6 per cent of the rate would probably not pay the additional cost of handling, and hence the additional distance would be a disadvantage. From the above discussion, the general conclusion is evident that for the case where the mileage on the home line is small compared with the foreign, additional distance may be an advantage, whereas it is a distinct disadvantage when the mileage on the home line is a large proportion of the total. Obviously, the limiting case when the loss would be without any compensation would be when the mileage of the home road had increased until it comprised the entire distance and the shipment became competitive home traffic.

From a similar line of reasoning, Wellington made the following statement in substance concerning competitive exchange traffic: While it is extremely desirable that a new line should constitute a part of the shortest distance between two important traffic centers, it is not always desirable, and may be disadvantageous to make any effort to bring this about so far as its own location is concerned, except in the selection of its connections.

This line of reasoning would definitely establish, from a theoretical point of view, the proportion of home to exchange traffic that would mark the limit where additional distance ceases to be an advantage and becomes a loss, provided that the conditions of operation could be analyzed into the simple elements assumed above. The difficulty in its application is that there is almost an infinite number of combinations of shipping points possible, for each station maintains possible traffic relations with every other, and the fixing of the tariff rate between a given station and any other constitutes a distinct combination that must be calculated by itself. On this account, such rather specious reasoning may lead to incorrect conclusions, so far as general conclusions are concerned, especially so inasmuch as it leads to conclusions that are partial truths. For the simple elementary conditions outlined above, the following deductions are usually made which will serve to illustrate the range of possible effect that distance may have on revenues:

1. Added distance is not necessarily a disadvantage to the home road, but may be positively an advantage in the case of non-competitive traffic.

2. Any additional distance represents uncompensated loss in the case of competitive home traffic.

3. Increased distance may constitute either a disadvantage or an advantage in the case of competitive exchange traffic, depending on the relative lengths of the lines participating and the traffic agreements between.

Indirect Effect of Distance. As previously indicated, the ultimate interests of the railroad and of the community served are largely identical, and additional distance that does not serve some economic purpose causes loss to the community and will ultimately bring loss to the railroad. It would be a gross mistake, for example, for a locating engineer to meander across a plain with a view solely of inserting distance in the line in order that the railroad may charge higher rates for transportation, even though all business is to be local and non-competitive. Such distance would bring about economic loss in operation, which must come ultimately from the patrons or the community served, making the latter poorer and hence less able to bring business to the railroad. Low rates encourage traffic, a fact that should be kept in mind in railway location as well as in railway operation.

Under competitive conditions, the moral effect of quick running time, of " on time trains " made possible by having the shortest route, and other indirect effects may greatly add to the business of the road. Where a patron has the choice of two or more routes, all equally convenient of access, a very small difference in the quality of service rendered will cause most of the traffic to go to the road offering the more desirable accommodations.

Effect of Distance on Operating Expenses. While the effect of a small change in the length of a railroad upon revenues may be more or less conjectural, the effect upon operating expenses is a fairly definite quantity. A considerable portion of the items of operating expenses will be entirely unaffected by a slight variation in distance while others will vary almost directly as the distance, depending upon the nature of the item of expense and upon the amount of distance added. To facilitate the discussion, increments of distance may be divided into three classes, viz.:

Class A. Small distances that do not alter the wages of train crews.

Class B. Distances great enough to affect wages of train crews, but not great enough to require additional side tracks or stations.

Class C. Distances great enough to alter the wages of train crews and to require additional side tracks and stations.

The effect of an additional distance on operating expenses will now be analyzed.

Maintenance of Way and Structures. In the United States, the mileage of yards and side tracks is approximately 30 per cent of the total mileage of line, and this is probably divided about equally between yard and terminal tracks and small yards and sidings. Experience shows that about one-third as much effort is expended in the maintenance of side and yard tracks per mile as main line (see p. 116), hence the distribution of maintenance should be in the proportion,

	Per Cent.
Main track	90
Small yards and sidings	5
Terminals and large yards	5

In the above classification, only the main track will be affected in the first two classes, and main track and small yards and side tracks will be affected in the last class.

Other Operating Expenses. Without discussing each item separately, the effect of additional distance on freight and passenger operating expenses is summarized in Tables XL and XLI for a representative western railroad.

Most of the items of the above tables do not require special comment, although the reason for choice of proportion affected in some cases may not be apparent on inspection. Repairs of steam locomotives, according to Mr. Wellington, are due to strains in stopping and starting, to exposure and to many other causes, so that he estimated that only 42 per cent were due to actual haulage. This figure was reduced to 38 per cent owing to the introduction on modern locomotives of expensive accessories which deteriorate independently of the mileage. For the third class, Wellington's estimate of 15 per cent for strains due to starting and stopping was adopted.

According to the best information available, repairs to equipment may be apportioned to the following causes:

	Per Cent.
Running on tangent	27
Starting and stopping	20
Switching	15
Exposure	8
Curvature, grades, and other causes	30

TABLE XL
EFFECT OF DISTANCE ON OPERATING EXPENSES, FREIGHT SERVICE

Item.	Per Cent of Whole.	Proportion Affected, Per Cent.			Cost per Additional Train-mile, Per Cent.		
		A	B	C	A	B	C
Ballast	.10	90	90	95	.09	.09	.10
Ties	.321	90	90	95	2.89	2.89	3.05
Rails	.38	90	90	95	.34	.34	.36
Other track material	.62	90	90	95	.56	.56	.59
Roadway and track	4.26	90	90	95	3.83	3.83	4.05
Removal of snow, etc	.03	90	90	95	.03	.03	.03
Grade crossings	.24	100	100	100	.24	.24	.24
Signals and interlockers	.11	0	0	100	.00	.00	.11
Telegraph and telephone	.21	90	90	95	.19	.19	.20
Bridges, etc	.43	0	0	100	.00	.00	.43
Roadway tools, etc	.23	90	90	95	.21	.21	.22
Steam locomotive repairs	5.23	38	38	53	2.00	2.00	2.77
Freight car repairs	6.70	27	27	45	1.81	1.81	3.02
Work equipment repairs	.14	27	27	45	.04	.04	.06
Shop machinery and tools	.38	27	27	45	.10	.10	.17
Injuries to persons	.09	27	27	45	.03	.03	.04
Stationery and printing	.03	0	0	40	.00	.00	.01
Station employees	5.04	0	0	80	.00	.00	4.03
Station supplies and expenses	.33	0	0	80	.00	.00	.26
Road enginemen	4.48	0	100	100	.00	4.48	4.48
Fuel for road locomotives	6.64	50	50	65	3.32	3.32	4.32
Operation of fuel station	.19	50	50	65	.10	.10	.12
Water for road locomotive	.49	50	50	65	.25	.25	.32
Lubricants for road locomotives	.15	30	30	80	.05	.05	.12
Road trainmen	5.43	0	100	100	.00	5.43	5.43
Casualties, total	2.63	50	50	100	1.32	1.32	2.63
Totals	47.77	...	...	...	17.40	27.30	37.16

TABLE XLI

EFFECT OF DISTANCE ON OPERATING EXPENSES, PASSENGER SERVICE

Item.	Per Cent of Whole.	Proportion Affected, Per Cent.			Cost per Additional Train-mile, Per Cent.		
		A	B	C	A	B	C
Ballast	.07	90	90	95	.06	.06	.07
Ties	1.23	90	90	95	1.11	1.11	1.18
Rails	.14	90	90	95	.12	.12	.13
Other track material	.22	90	90	95	.20	.20	.21
Roadway and track	1.89	90	90	95	1.70	1.70	1.80
Removal of snow, etc	.02	90	90	95	.02	.02	.02
Grade crossings	.18	100	100	100	.18	.18	.18
Signals and interlockers	.08	0	0	100	.00	.00	.08
Telegraph and telephone	.17	90	90	95	.15	.15	.16
Bridges, etc	.19	0	0	100	.00	.00	.19
Roadway tools, etc	.10	90	90	95	.09	.09	.10
Steam locomotive repairs	3.37	38	38	53	1.28	1.28	1.79
Passenger car repairs	1.54	35	35	45	.54	.54	.69
Work equipment repairs	.08	27	27	45	.02	.02	.04
Shop machinery, etc	.15	35	35	45	.05	.05	.07
Injuries to persons	.03	35	35	45	.01	.01	.01
Stationery and printing	.01	35	35	45	.00	.00	.00
Station employees	1.06	0	0	80	.00	.00	.85
Station supplies	.11	0	0	80	.00	.00	.09
Road enginemen	2.36	0	100	100	.00	2.36	2.36
Fuel for road locomotives	2.85	50	50	65	1.43	1.43	1.85
Operating fuel station	.12	50	50	65	.06	.06	.08
Water for road locomotives	.21	50	50	65	.10	.10	.14
Lubricants for road locomotives	.09	30	30	80	.03	.03	.07
Casualties, total	2.06	50	50	100	1.03	1.03	2.06
Totals	18.33	...	...	...	8.78	10.54	14.23

Assuming half of the trains stop at stations and sidings of the third class of distance, the proportion would be 27+10+8=45 per cent.

Road enginemen are paid on the basis of a 100-mile run with overtime for extra mileage, a fact which virtually places enginemen on a mileage basis, especially if the division is more than 100 miles long. For this reason, additional distance on divisions over 100 miles long, the wages would be directly affected while on shorter divisions they may not be. Trainmen are paid monthly salaries on passenger trains and on the same basis as enginemen on freight trains. From the discussion of Chapter

XIV, a reasonable division of fuel consumption is to consider half of the fuel used in haulage through this additional distance 15 per cent in stopping and starting, and the remainder in various other ways. The other items probably need no further comment.

Summary. The above tables indicate that for freight service, operating expenses would be increased as follows for additional distance:

	Per Cent.
For Class A distance	17.4
Class B	27.3
Class C	37.2

and for passenger traffic,

	Per Cent.
For Class A distance	8.8
Class B	10.5
Class C	14.2

For this particular road, the freight traffic is chargeable for 69.23 per cent of the operating expenses, hence freight expenses would be increased per train-mile

For Class A distance $\frac{17.4}{.69}=25.2$ per cent.

Class B $\frac{27.3}{.69}=39.4$ per cent.

Class C $\frac{37.2}{.69}=53.7$ per cent.

Likewise passenger traffic is chargeable 30.77 per cent of the operating expenses, hence, passenger expenses would be increased per train-mile

For Class A distance $\frac{8.77}{.308}=28.6$ per cent.

Class B $\frac{10.5}{.308}=34.3$ per cent.

Class C $\frac{14.2}{.308}=46.3$ per cent.

The average cost per freight train-mile on this road was found to be $1.58, and of passenger trains, $0.90 per train-mile. If the length of the line were increased the added cost per mile of such distance per daily train one way would be as follows:

Freight

Class A $1.58 × .252 × 365 = $145.30
Class B 1.58 × .394 × 365 = 227.20
Class C 1.58 × .537 × 365 = 309.50

Passenger

Class A $0.90 × .286 × 365 = $ 94.00
Class B .90 × .343 × 365 = 112.60
Class C .90 × .463 × 365 = 152.00

These amounts capitalized at 5 per cent indicated the amount that might be justifiably spent in eliminating one mile of distance of the different classes.

Class.	Freight.	Passenger.
Class A	$2906	$1980
Class B	4554	2252
Class C	6190	3040

CHAPTER XVII

MECHANICAL AND ECONOMICAL EFFECTS OF CURVATURE

General Considerations. It may be stated at the outset that it is impracticable to eliminate all curvature from a railroad location, the question always resolving itself into one of more or less curvature, and of sharp or flatter curves, rather than the presence or absence of curves altogether. From an operating point of view, a straight level track would be the ideal, but over natural topography and with an attempt to enter all centers of population that may afford traffic along the way, it is out of the question to secure either straight or level track, and the best engineering skill is required to determine the proper amount of curvature and the economical rate of gradient.

In the beginning of railroad construction, locomotives were believed to be incapable of passing around curves and the railroads were as a result built practically straight. This view was found to be incorrect, however, and at the present time many of the most successful railways are found to contain a great deal of curvature. Fortunately, since curves are unavoidable, the disadvantageous effects of curves are perhaps the least serious of all the minor details of railway location, although such is not the popular impression. Many of the supposed objections are more or less imaginary, while others have a real significance in the design of a location. Two fairly distinct considerations arise in connection with the introduction of curvature into a railway location, viz.: (1) the mechanical effects on the rolling stock, and (2) the economical effects, or the influence on revenues and operating expenses.

Mechanical Effects of Curvature. The mechanical effects of curvature bear very directly upon the problem of location. They include the effects on the train, involving questions of superelevation, the additional resistance caused by curves and the proper compensation of grades therefor, the allowable speeds on curves, and the relation of the wheel base of the rolling stock to the maximum degree of curve allowable.

Superelevation of the Outer Rail. The outer rail of a railroad track on a curve is placed at a higher elevation than the inner rail in order that the resultant of the centrifugal force and the weight of the train may be as nearly as practicable normal to the plane of the track, and consequently make the wheel pressures on the two rails equal. This is called superelevating, elevating, or canting the track. Superelevation does not guide a truck around a curve, as it is sometimes supposed, for the position of the truck on the track is independent of the superelevation, within ordinary limits of speed. If all trains passing around a given curve were operated at the same speed, the proper amount of superelevation could be calculated according to the principles of mechanics. The truth is, however, that the trains are operated at widely different speeds. On single-track lines, which constitute 89 per cent of all the railways of the United States, the conditions are most unfavorable for a satisfactory adjustment in this respect, for on such lines such extremes of speed as fast passenger and slow freight occur, and, moreover, the downgrade passenger trains run at higher speeds than normal and the freight trains up grade run slower than normal, which facts accentuate the difference of conditions governing the amount of superelevation required. On double track, this latter condition is avoided, and on four- and six-track railways, which constitute less than 1 per cent of the railroad mileage of America, the conditions with respect to superelevation are ideal. For any given speed, the problem is simple.

Let R be the radius of the curve in feet;
E, the superelevation in feet at gauge line;
g, the gauge distance, 4.705 feet for standard gauge;
W, the weight of a car carried by a track.

4.708

Then, since $\frac{Wv^2}{32.2R}$ is the centrifugal force due to a speed of v feet per second, $\frac{Wv^2}{32.2R} \div W = \frac{E}{g}$, as may be shown by resolving the force of weight normal and parallel to the track. Reducing E to inches and v to miles per hour, there results for the superelevation, e, in inches.

$$e = 0.00066V^2D,$$

in which V is the velocity in miles per hour and D is the degree of curve.

The question naturally arises as to the proper speed for which the superelevation should be computed. If the freight traffic over a line predominates and the passenger traffic is very light, then the needs of the former should govern and the passenger trains should be required to slacken to a safe speed for curves that may be lacking in superelevation. On the other hand, if the passenger traffic is of commanding importance, the speed of the fast passenger trains should control the cant in the track. Usually a compromise speed is adopted for the sharper curves and the passenger trains are required to slow down to a safe speed. A limit is usually set empirically to the amount of superelevation that may be used, different railroads having different standards in this respect, 6 to 8 ins. being common practice.

Superelevating for passenger trains will require that the grades be compensated for curvature to take care of the unbalanced superelevation, as explained in the next article.

On single track lines used exclusively for freight, the superelevation should be calculated for speeds not exceeding 15 miles per hour, for it is less expensive to decrease speed on the trains running down grades than it is to overcome the additional resistance due to unbalanced superelevation. An instance is recorded* where two engines hauling 3500 tons of coal on an 8° 30′ curve with a central angle of 185° habitually stalled when the superelevation was 5½ ins., but when it was reduced to 3 ins. no further difficulty was experienced.

Formerly it was the custom to maintain the inner rail at grade in rounding a curve and to cant the track entirely by elevating the outer rail. This practice required the engine to raise the total weight of the train, i.e., its center of gravity, through half of the superelevation, and with a short easement spiral, this practice made considerable difference in the rate of grade, which on a slope approaching the ruling gradient was a serious matter. A better practice, and one that is being followed by several railroads, is to raise the outer rail one-half the desired superelevation and to depress the inner rail a like amount, which method permits the center of gravity of the train to continue on the regular gradient of the track.

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* Proc. Am. Ry. Eng. Assn., Vol. XIV, p. 623.

Theory of Curve Resistance. Information concerning the amount of resistance caused by curves is very meager and a theoretical analysis of the problem is rather uncertain. However, in order to assist in comprehending the nature of the action of trains on curves, a brief theoretical analysis is here presented.

Curve resistance arises from five sources, viz.:

a. Rotation or twist of wheel about a vertical diameter;
b. Longitudinal slipping due to difference in the length of rails;
c. Lateral slipping of front wheels in guiding the truck;
d. Flange friction in sliding the wheels laterally;
e. Unbalanced superelevation, where it exists.

Obliquity of traction, which is sometimes mentioned as one of the factors entering into curve resistance, probably does not increase the pull in passing around a curve, for it merely decreases the flange pressure required to slide the truck, thereby diminishing the work done at the flange which would about counterbalance the additional pull required due to obliquity.

The work done in rotating one wheel of each truck about its vertical diameter is very small and may be neglected, as will be shown. From experiments made at Purdue University, it was found that the area of contact of a wheel with the rail is roughly an ellipse with an area varying from 0.3 to 0.5 sq.in., depending upon the load on the wheel. Since only one wheel of a truck is usually thus turned about its vertical diameter, $\frac{W}{4}$ is the weight coming on the average wheel, that is turned, where W is the weight per car truck in pounds. With a coefficient of 0.2 and making an approximate solution, the work done in turning through 1° of central angle is found to be $0.00000009WD$ ft.-lb., where D is the degree of curve, which amounts to 0.000180 ft.-lb. per ton of load.

The total longitudinal slippage is $\frac{wI^{\circ}\pi}{180}$, where w is the distance between centers of rails, since this is the difference in length of the outer and the inner rail on a curve of I° central angle. Since $I=\frac{DL}{100}$, L being the length of the curve in feet, the total slippage is $0.00086DL$ and the work done during the slip, since only one wheel slips the entire distance, is $0.0086DL\times\frac{W}{2}\times0.2$ $=0.000086DLW$ and per ton, $0.172DL$.

Lateral slippage is caused by the fact that the front wheels of a truck guide the truck and are necessarily slidden sidewise. In passing around a curve, the wheels of a four-wheel truck assume the position indicated in an exaggerated manner in Fig. 43. The flange of the outer front wheel really guides the truck.

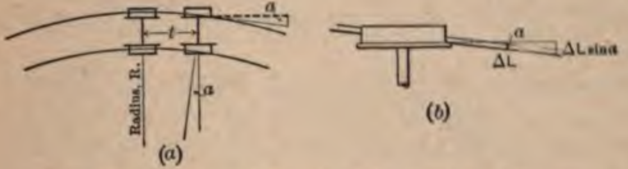

FIG. 43.—Position of Truck while Passing a Curve.

This position of the truck is taken approximately regardless of the superelevation or of the speed. Let ΔL represent a small increment of progress of the truck along the track. Then the front wheel will be slipped over a distance $\Delta L \sin a$, a being $\sin^{-1}\frac{t}{R}$. For a 1° curve and a 5 ft. 6 in. truck, $a=0° \; 3.1'$, and the total slip for any degree of curve, D, will be $0.0009DL$. The front wheels slip on a diagonal a distance $(0.0009^2+0.00086^2)^{\frac{1}{2}}DL$, or $0.00125DL$. The average slip for the four wheels is then $(0.00086+0.00125+0.0009+0)\frac{DL}{2}$, or $0.0015DL$, and the work done is $0.0015DL\times0.18W=0.000265DLW$, which for one ton, is $0.53\ DL$ ft.-lb., the lower coefficient of friction being assumed because of the continuity of the slipping.

A certain amount of work is done in overcoming flange friction on the outer front wheel in sliding the wheels laterally, which can be shown to amount to about 1.0 ft.-lb. per ton per foot of distance and to be independent of the degree of curve.

When there is an unbalanced superelevation, e ins., there is an inward component of gravity which causes the flange of the inner rear wheel to grind on the rail with a force of approximately $0.3e$ lb. per ton, which is independent of the degree of curve.

The total work done therefore in going a distance L around a curve would be $0.00018DL+0.172DL+0.53DL+0.3eL+1.0L$, or $(1.0+0.3e+0.70D)L$, and the force required to pull the ton, or in other words, the resistance in pounds per ton due to curvature, would be $1.0+0.3e+0.7D$. This is equivalent to a $(0.05+0.015e+0.03D)$ per cent grade.

The unbalanced superelevation amounts to $0.00066(V_1^2-V_2^2)D$ where V_1 is the speed for which the curve was superelevated, and V_2 the speed of the freight train; or the unbalanced superelevation equals the actual superelevation of the outer rail minus $0.00066V_2^2D$.

Compensation of Grades for Curvature. Where curves occur on the ruling gradient, or on grades nearly equal to the ruling gradient, the rate of grade must be reduced in order to permit the locomotive to pull its train with no more resistance than it encounters on a tangent on the same grade. Some engineers do not compensate grades for curvature except where the grade resistance plus the curve resistance equals the resistance of the ruling gradient for the district, but it seems advisable to compensate, perhaps at a lower rate, even on minor grades, in order to make the pull of the locomotive as uniform as possible, for under such conditions, locomotives operate most efficiently. Moreover, in the event that future grade revision should lower the ruling gradient, it would not be necessary to revise the minor grades by proper compensation.

The proper rate of compensation depends upon the total amount of resistance that is caused by the curvature. Owing to the fact that the resistance of curves depends upon the design and condition of the rolling stock and perhaps in a small measure upon the speed of the train in addition to the main factors discussed in the preceding paragraph, it is somewhat difficult, if not impossible, to state the rate that should be generally adopted. The possibility of necessary stops at block signals, water stations, etc., should also be taken into consideration, although such influences should be adjusted separately from curvature compensation.

If the resistance is equal to $0.7(1.5+0.5e+D)$ pounds, as explained in the preceding article, the compensation should be $0.035(1.5+0.5e+D)$ feet per hundred feet.

As an illustration, assume a 6° curve with 3 ins. unbalanced superelevation. The rate of compensation per 100 ft. should be

$$0.035(1.5+0.5\times 3+6)=0.31 \text{ ft.}$$

The American Railway Engineering Association adopted the following rules for compensating curves:

1. Compensate 0.03 per cent per degree when,
   - *a*. The length of the curve is less than half the length of the longest train.
   - *b*. The curve occurs within the first 20 ft. of rise of the grade.
   - *c*. Curvature is in no sense limiting.
2. Compensate 0.035 per cent per degree when,
   - *a*. The curve is between one-half and three-quarters of the length of the longest train.
   - *b*. The curve occurs between 20 and 40 ft. of rise from the bottom of the grade.
3. Compensate 0.04 per cent per degree when,
   - *a*. The curve is habitually operated at low speed.
   - *b*. The length of the curve is longer than three-quarters the length of the longest train.
   - *c*. The superelevation is excessive for freight trains.
   - *d*. In any way the curve is likely to be limiting.

4. Compensate 0.05 per cent per degree whenever the loss in elevation can be spared.

In the report of the Committee on the Economics of Railway Location of this Association in 1915, this statement is found: "Ruling gradients must be compensated for curvature, and the rate of 0.04 ft. per degree of central angle is recommended," which is the same as compensating .04 per cent per degree of curve.

Speed of Trains on Curves. The comfort of passengers when a train on which they are riding passes a curve at high speed is dependent more upon the condition of the track with regard to line and surface than upon the degree of the curve, provided that the track is given the proper cant to correspond to the speed at which the train is operated. As shown in a previous paragraph, the resultant of the weight and centrifugal force passing through the center of gravity of a train or of a passenger is normal to the track when the latter is properly canted. However, as already seen, it is not always practicable to adjust the superelevation of the track to the speed of the train, and as a consequence it happens that there is a certain amount of unbalanced superelevation on curves for most of the trains. The effect of the unbalanced superelevation, when either plus or minus, will depend upon the height of the center of gravity of the rolling stock above the rail. Messrs. G. J. Ray, Chief Engineer D., L. & W. R. R., and F. S. Stevens, Engineer of Maintenance of Way, P. & R. R. R., have made a study of this subject and the following results are from their valuable contribution.* Table XLII gives the height of centers of gravity of

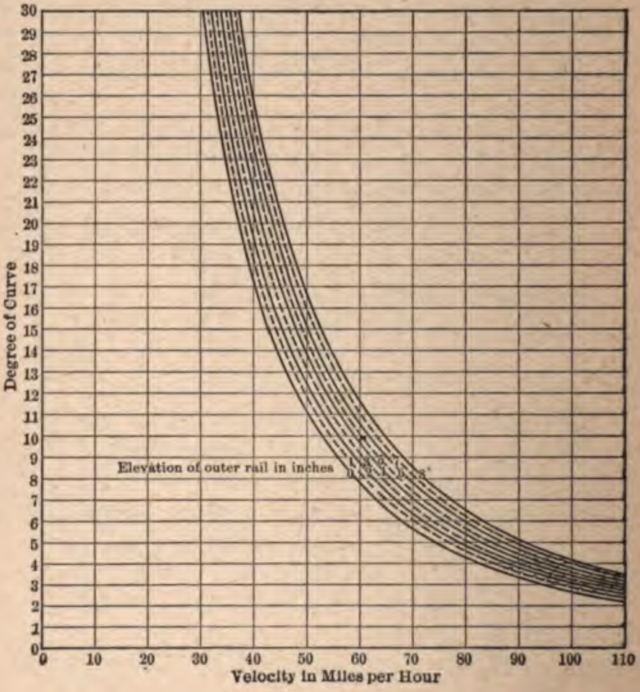

FIG. 44.—Speeds of Trains for Overturning Speed.

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* Proc. Am. Ry. Eng. Assn., Vol. XV, p. 570.

Table XLII

APPROXIMATE HEIGHT OF CENTER OF GRAVITY OF STANDARD GAUGE LOCOMOTIVES AND TENDERS RECENTLY CONSTRUCTED

The Baldwin Locomotive Works

Type of Locomotive	Engine in Working Order.		Tender Loaded.	
	Weight, Lbs.	Height C. of G., Ins.	Weight, Lbs.	Height C. of G., Ins.
4–6–2	267,000	80	147,000	60
2–8–0	217,000	74	177,000	60
2–8–2	265,000	78	167,000	57
2–8–2	275,000	76	184,000	62
2–8–2	284,000	78	167,000	65
2–8–2	286,000	75	154,000	55
2–8–2	310,000	75	175,000	56
2–8–2	322,000	76	157,000	62
2–10–2	293,000	78	185,000	62
2–10–2	356,000	77	160,000	55
0–6–6–0	350,000	77	140,000	62
0–8–8–0	409,000	84	170,000	61
2–8–8–0	450,000	80	154,000	64

American Locomotive Company

Road.	Class.	Weight.	Cylinders, Ins.	Driving Wheel Diam., Ins.	Center of Gravity from Rail, Ins.
Missouri Pac....	462	256,000	26 ×26	73	76½
Missouri Pac....	282	275,000	27 ×30	63	71
Missouri Pac....	280	209,600	22 ×30	63	72
B. & O.........	462	229,500	22 ×28	74	70
N. Y. C........	280	236,000	23 ×32	63	72
L. S. & M. S....	462	261,500	22 ×28	79	75½
Grand Trunk...	460	182,000	20 ×26	73	64½
B. & O.........	280	186,000	21 ×30	57	68½
Pennsylvania...	262	#1 230,000 #2 234,500	22½×28	80	74½
B. & O.........	280	193,500	22 ×28	56	60½
M. & St. L.	260	150,500	20 ×26	64	60½
B. & O.........	442	180,000	22 ×26	80	70½

Center of Gravity of Tenders

Road.	Capacity.	Tank Type.	Height of Center of Gravity, Ins.
Erie.........................	9000	Vanderbilt..	76¼
Erie.........................	8500	Water bot...	77
Experimental	8000	Water bot...	70

various types of locomotives above the top of the rail. The curves in Fig. 44 give the speeds for different conditions of elevation of the outer rail and degree of curve at which the resultant of centrifugal force and gravity falls at the gauge line and consequently makes the locomotive on the point of overturning, the height of the center of gravity being 84 ins. This speed would obviously be the maximum permissible on such curves. Fig. 45 shows the limiting speeds for an unbalanced superelevation of 3 ins. It is impossible to state what unbalanced superelevation will allow comfortable riding, since the effect of the curve will be noticeable if there is any, but it is believed that a decided lurch of the car will not be noticed, when the track is properly spiraled, if the unbalanced superelevation is not greater than 2 or 3 ins.

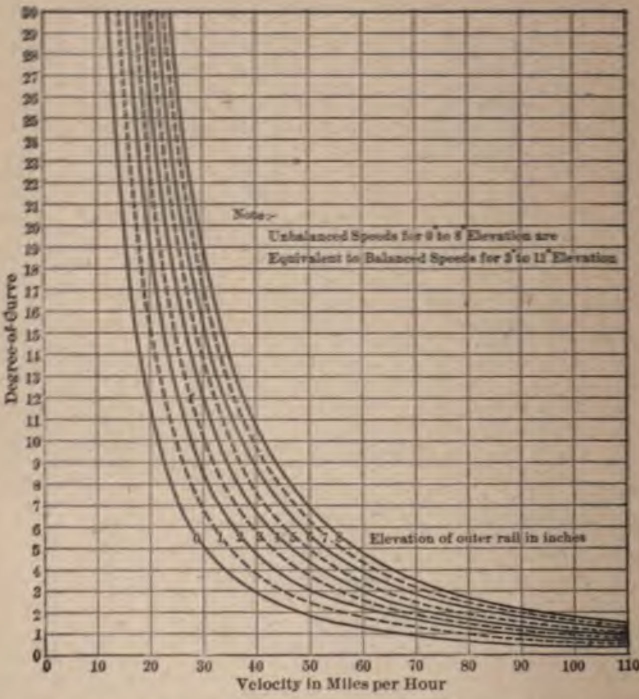

FIG. 45.—Speeds for an Unbalanced Superelevation of Three Inches.

Mr. J. W. Macomb-Hood,* from an extended series of observations, found that the maximum operating speeds on the British railways might be expressed by the formula, $V=\frac{130}{\sqrt{D}}$, D being the degree of curve, although three of his observations showed higher speeds than this would indicate. This equation would probably represent maximum speeds in America where the roadbed is in good condition. A formula for maximum operating speed much used in the calculation of bridge stresses due to centrifugal force is $V=60-2.5D$, which gives very conservative speeds.

Limiting Effect on Motive Power. Owing to the long wheel bases of recent types of locomotives, sharp curvature has a limiting effect on the character of locomotive that can be operated over the curves. It is evident that the drivers of a locomotive on a rigid wheel base must be held in a straight line while running and hence must lie on a chord of the curve of the outside rail and on a tangent to the curve of the inside rail. Since the length of this chord or tangent governs the length of the mid-ordinate or tangent offset, as the case may be, it is clear that the length of the wheel base and the amount of play between the flanges of the wheels and the gauge of the rails will determine the sharpness of the curve that can be passed. Some roads use "blind drivers," i.e., without flanges, for the intermediate wheels or for the end wheels in order to enable their locomotives to pass around the curves with greater facility.

From the equation in railroad curves giving the ordinate to a curve at any point on a chord, the allowable radius of curve for a rigid truck would be, $R=\frac{6ab}{p}$, and for a swing motion truck, $R=\frac{6ab}{\left(p+\frac{sb}{a+b}\right)}$, where a is the distance in feet from center pin of a four-wheel truck, or from the axle of a two-wheel truck, to the center of the first driver axle; b is the distance in feet center to center of front and rear driver axles; p is the flange play in inches, assumed ordinarily at $\frac{5}{8}$ in.; s is the swing of the truck in inches, taken ordinarily as $1\frac{1}{2}$ ins.

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* Proc. Inst. C. E., 1908, p. 125.

Table XLIII gives the length of wheel base of various types of locomotives, the rigid wheel base being the distance center to center of front and rear axles, while the total wheel base is the distance from center to center of first and last locomotive axles. A locomotive has recently been built of the 2–10–2 type having an arrangement for the lateral movement of the end driving axles. Although the rigid wheel base of this locomotive is 22 ft. 6 ins., the locomotive successfully passes around 20° curves. The maximum degree of curve for which certain types of locomotives used on the C., M. & St. P. Ry. are designed is shown in Table XLIV.

TABLE XLIII

WHEEL BASES OF LOCOMOTIVES. STANDARD GAUGE

Railroad.	Engine Type.	Wheel Base.						Diam. of Drivers.
		Drivers.		Total.		Engine and Tender.		
		Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	Ins.
C. & A.	462–248	13	9	34	8½	66	4	80
C., I. & L.	462–206	12	10	32	11	64	0½	73
L. S. & M. S.	282–323	16	6	36	1	68	10½	63
C. & O.	282–324	16	6	34	10	67	4½	56
C., R. I. & P.	282–320	17	0	35	2	66	11½	63
Penna.	462–316	13	10	36	5	71	5¾	80
D., L. & W.	462–288	13	0	34	10	67	4	73
U. P.	462–278	13	4	35	8	70	3¼	77
N. Y. C. & H. R. .	462–272	14	0	36	6	68	0	79
Virginian.	2882–540	15	6	57	4	91	5¼	56
N. Y. C. & H. R. .	0100–274	19	0	19	0	54	7½	52
D., L. & W.	080–220	16	0	16	0	49	2¾	57
Ill. Cent.	060–166	11	8	11	8	42	11½	51

The length of wheel base is not the sole factor that determines the degree of curve that a locomotive can pass, the design of the wheel tread, the rigidity of the trailer if present and the design of the front truck having much to do with the question. However, the length of the wheel base is the most important factor and can be used for approximate calculations.

A complete truck consisting of four wheels is more easily guided around a curve than one of two wheels, hence, for high speed passenger service, a complete truck is almost invariably used; but for freight service, in order to increase the weight on the drivers and the number of drivers, a two-wheeled or pony truck is commonly used.

TABLE XLIV

MAXIMUM DEGREE OF CURVE FOR WHICH LOCOMOTIVES ARE DESIGNED, C., M. & ST. P. RY.

Locomotive Type.	LENGTH OF WHEEL BASE.						Degree of Curve.
	Rigid.		Engine Total..		Engine and Tender.		
	Ft.	Ins.	Ft.	Ins.	Ft.	Ins.	
460–179............	12	11	25	5	55	10½	11
280–177............	15	3	23	11	56	6	17
280–197............	17	6	26	7	60	2	16
462–247............	14	0	23	7	67	1¾	12
462–240............	14	0	35	6	67	0¾	12
460–178............	14	10	26	5½	55	9	10
460–183............	12	11	25	3½	55	9	12
262–206............	11	0	29	3	59	9¼	18
282–261............	16	6	35	1	65	7¼	16
282–275............	16	6	35	1	66	8¼	16
2882–396...........	10	0	48	0	79	8¼	20
060–103............	11	0	11	0	41	0½	40
060–127............	11	0	11	0	41	7½	40

Economic Effects of Curvature. As previously stated, railway location involves not only physical problems, but it requires an investigation of the economic conditions as well. Not only the physical or mechanical effects of curves must be considered, but their economic influence must be studied also. Curves may affect the location economically in reducing the revenues by having an adverse effect on traffic, and in causing an increase in operating expenses.

Effect of Curvature on Revenues. That excessive curvature has a deterrent effect on traffic is evidenced by the tendency of railway traffic managers to make their lines appear as straight as possible on the maps in the time-tables and other advertising matter. There is very little doubt but that curvature to the general public represents a very objectionable feature in railway operation, regardless of the fact that when curves are properly spiraled, most people ride over them without noticing the deviation from a straight track. However, excessive curvature operated at high-speeds is likely to make passengers car sick, and hence, those persons having an idiosyncrasy to car and sea sickness will likely choose other routes for travel.

Not only does excessive curvature have a detrimental effect on passenger traffic, but certain classes of freight are injured in the passage around sharp curves; for example, live stock on freight cars may be unduly jostled together and thereby suffer loss in weight and condition. This fact not only augments the damage claims from shippers, but may very materially lessen the amount of live stock shipments over the line.

Whatever deleterious effect curves may have on the amount of revenue secured, the effect would be certainly confined to competitive business. However, it is impossible to state a definite percentage that might represent the effect of curvature on traffic, and as a consequence, it is commonly neglected altogether, although doubtless it should be given some consideration.

Danger of Operation on Curves. Accidents usually result from conditions that were not anticipated, consequently, while expenditure of money will decrease the frequency and seriousness of accidents that do occur, yet, it may be safely stated that no expenditure of money would eliminate all accidents altogether. Curvature is only one possible source of accident and probably one of the least prolific sources. In fact, railway travel is not so hazardous as many believe. Accident insurance rates on railways are lower than for conditions of working at most occupations. Perhaps two-thirds of the railways in any one year do not have an accident in which a passenger is killed. Many railroads pass through periods of five to ten years without causing the death of a passenger. In 1912, 114 passengers were killed in train accidents, while 34,447,200,000 passengers were carried one mile, or about 244,000,000 passengers carried one mile for every one killed in a train accident. At this rate, in undertaking a journey of 1000 miles, the chances would be 1:244,000 that a person would be killed in an accident, or putting it another way, a person traveling 1000 miles every 24 hours would have to ride 670 years before the chances would be even that he would be killed in a railway accident. Assuming one-fifth of the railroad mileage to consist of curves, he would have to travel 3300 years before being killed on a curve, and he would have about one-fortieth of this immunity against injury.

While 10,964 persons were killed by railroads in the United

States in 1913, only 759, or 7 per cent, of these lost their lives due to defect or mischance in railway operation, the remaining 93 per cent being due to negligence on the part of the individual victims. Considerably more than 50 per cent were trespassers. Only 336, or 3 per cent, were passengers. Of the 200,308 injuries, only 14,407, or about 7 per cent, befell passengers. Of the 336 passengers killed, only 141 were killed in derailments or collisions, the only two classes of accidents that could be attributed to curvature in any instance. While no statistics are available to indicate the number of wrecks due to curvature, it is obvious from the above that the number is small. From an experience of several years in railroad service and from observation of railway operation, the author does not recall a single instance of a wreck that was caused entirely by curvature, none, indeed, that would not probably have occurred on tangent alignment under similar conditions. From the above considerations, it appears that the danger due to curvature is slight.

Effect of Curvature on Operating Expenses. To make a reliable estimate of the effect of curvature on operating expenses is extremely difficult because of the lack of any exact and complete observations on the subject. That curvature increases operating expenses is not doubted by anyone, for manifestly, the danger of derailment and collision is somewhat, even if slightly, augmented; the resistance is increased, thereby adding to the fuel and other expenses; the wear on track and roadbed is more severe, and in numerous other ways, curvature indubitably adds to the cost of operation, but to assign a definite value to the increased cost is difficult, to say the least. However, by the methods previously employed in studying the effect on the separate items of operating expenses, it may be possible to arrive at a fairly reliable estimate of the total effect.

The first question that naturally arises is whether or not the effect of curvature is dependent on the degree of curve, and to what extent it varies with the degree. It is commonly assumed that the cost of curvature is dependent on the amount of curvature rather than upon the degree of curve; that is, 1000 ft. of 1° curve would exert the same influence on operating expenses that 100 ft. of 10° curve would exert. While this proposition has never been definitely proved, it is commonly accepted as being essentially correct. The total work done in passing the curve is practically the same for any given central angle, regardless of the degree of curve, hence, the increase in fuel consumption is apparently dependent chiefly on the central angle and probably the wear on the track likewise varies with the central angle. What observations have been made seem to support this theory, hence, it is desired to investigate the effect on operating expenses per degree of curvature rather than per degree of curve.

A useful form of the question at issue is, At what amount of curvature will the resistance be double that on a straight track? Assuming 0.5 lb. per ton per degree of curve to represent the resistance due to curves, and 6 lbs. per ton as average train resistance, Wellington concluded that the resistance would be double that on a tangent track for a 12° curve, and Mr. J. B. Berry in relocating a portion of the Union Pacific Railway, assumed that 12° 30′ curves would double the resistance. The Committee on Roadway of the American Railway Engineering Association stated that 0.8 lb. per degree was a fair average resistance due to curves, which on the above basis would make the resistance double on a 7° 30′ curve. Following the analysis of the first part of this chapter in which $(1+.7D)$ lbs. was found to represent the average curve resistance, the resistance would be found to be doubled on a 7° 10′ curve. Owing to the fact that the basis of estimating cost of curvature is the average cost of operation, which includes operation over curves, a lower figure than 0.8 lb. per degree should probably be adopted, and perhaps 0.6 lb. would more nearly represent average conditions. On this basis and with 6 lbs. as the average train resistance, the resistance would be double that on a tangent track on a 10° curve. One mile of 10° curve would mean 528° of central angle.

In the following discussion as to the effect of 528° of curvature on the operating expenses, only those items that are affected will be mentioned.

Ballast. No exact information is available as to the added wear on ballast due to curves, but it was found on one railroad that a 4° curve required about 10 per cent and a 10° curve required about 35 per cent more ballast than did tangent track, hence it would probably be a fair estimate to assume 33 per cent a sthe average increase in wear on ballast for a 10° curve.

Ties. The thrust against the outer rail and the pressure against the inner rail cause an overturning moment that tends to cut the ties under the edge of the rail, and as a result, a good practice is to place tie plates on all curves, or perhaps on all above a certain degree. The spikes are pulled by the action on curves and have to be redriven more frequently than on tangent, which fact also tends to shorten the life of the ties. Wellington gives some data which seem to indicate that a 10° curve will add 50 per cent to the cost of ties, and other data are in the author's files that would indicate from 100 to 200 per cent increase in the wear on ties due to a 10° curve. From a somewhat extended study of the conditions of ties on curves, the author would estimate the increase in wear on curves to be about 100 per cent for a 10° curve.

Rails. The wear on rails appears to vary almost directly with the degree of curve in the rather meager observations that have been made. Table XLV * gives the results of some observations made on rail wear due to curves on the Northern Pacific Railroad. The loss on a tangent subject to the same traffic was 0 525 per cent per 10,000,000 tons of traffic carried, and all losses are reduced to this basis. Each value is the average of five observations. Averaging these values gives a result of 22.6 as the mean percentage of increase of wear per degree of curve, or 226 per cent increase for a 10° curve. On one southern railroad, it was found that the outer rails on 10° curves had to be renewed in three years and the inner rail in six years,

TABLE XLV

WEAR OF RAIL ON CURVES—NORTHERN PACIFIC R. R.

Degree of Curve.		Per Cent Loss in Four Years.	Per Cent Loss per Million Tons Traffic.	Ratio of Loss on Curve to Loss on Tang.	Excess Wear on Curves per Degree, Per Cent.
4°	31′	2.043	0.880	1.677	15.0
5	0	3.685	1.233	2.350	27.0
10	0	4.196	1.512	2.880	18.8
10	30	5.066	1.700	3.237	21.3
3	0	1.354	0.501	1.928	31.0 [1]

[1] On another division where tangent wear was 0.260 per cent per million tons of traffic.

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* Economics of Railroad Construction, W. L. Webb, p. 169.

making an average life of four and a half years for rail on a 10° curve. On tangent track on the same road, the life of rail was found to be about ten years, indicating that the increased wear on a 10° curve was 222 per cent of that on a tangent, which agrees fairly closely with the records on the Northern Pacific R. R.

Roadway and Track. The sub-items, track maintenance and applying track material, are about the only ones affected by curvature, and these constitute about 25 per cent of the total. Track sections are shortened sometimes from 10 to 25 per cent where there is considerable curvature in recognition of the fact that curves require more labor than tangent track. For these reasons it is believed that allowing an increase of 25 per cent is this item for curvature will be about correct.

Steam Locomotives. About 85 per cent of the total expenditure chargeable to this item is attributable to road locomotives, consequently only that percentage will be in any way affected by curvature. The tire wear is probably increased in about the same proportion that rail wear is increased, or 22.6 per cent per degree of curvature. On the previous assumption that the work done by the locomotive in passing a 10° curve is doubled, the general strain on the locomotive would be largely increased. It is possible, therefore, that the wear on locomotives would be increased from 100 to 150 per cent on 528 degrees of curvature per mile.

Conducting Transportation. Fuel is the chief item affected under this heading, and since about 80 per cent of the fuel is used in hauling the train, only this proportion will be affected, and since it is assumed that the resistance is doubled for these conditions, the increase in fuel would be about 80 per cent.

The wages of enginemen and trainmen will be increased somewhat, doubtless, owing to the increased difficulty in making time, and a 10 per cent increase is assigned to this item. Other items of transportation expenses will not be appreciably affected.

By similar reasoning for other operating expenses, an appropriate proportion of increase of operating expenses can be estimated. A summary of these calculations is given in Table XLVI.

Summary. From the above table it appears that 38 per cent increase in operating expenses might be expected from the introduction of 528 degrees of curvature per mile on the location of a railroad, or 0.070 per cent per degree of central angle. If the average operating expense be taken as $1.76 per train-mile, each degree of curvature would cost $0.90 per year per daily train each way, which would indicate that about $15 might be justifiably spent to eliminate 1 degree of curvature for each round trip daily train.

TABLE XLVI

EFFECT OF CURVATURE ON OPERATING EXPENSES

Based on the assumption that 528 degrees of curvature per mile will double the train resistance.

Item.	Per Cent of Operating Expenses, 1914.	Proportion Affected, Per Cent.	Increase in Cost Per Train-mile, Per Cent.
Ballast	0.33	33	0.11
Ties	3.07	100	3.07
Rails	0.98	225	2.20
Other track material	1.10	50	0.55
Roadway and track	6.85	25	1.71
Steam locomotives	9.33	125	11.77
Passenger train cars	1.86	25	0.46
Freight train cars	11.10	75	8.42
Work equipment	0.33	50	0.17
Shop machinery	0.55	50	0.28
Fuel road locomotive	9.42	80	7.53
Other supp. road locomotives	0.98	50	0.49
Road enginemen	5.95	10	0.60
Road trainmen	6.42	10	0.64
			38.00

From the foregoing it is evident that the introduction of a certain amount of curvature in a location does not represent a great economic loss, and particularly is this true on light traffic railroads. Many roads with heavy traffic have operated their lines containing considerable curvature without finding the existence of curvature a vital handicap. The amount of curvature that may properly be introduced in a location is dependent almost entirely upon the character and amount of traffic to be carried and should be determined rationally instead of by arbitrary assignment. For example, instead of attempting to locate a line with 6° as the maximum degree of curve, the engineer should adopt such curves as the topography will readily yield and then reduce the amount and sharpness of the curves as much as can be economically justified by the traffic to be carried.

Choice of Degree of Curve. While it is true that the amount of curvature rather than the degree is the more important consideration, yet the proper degree of curve to be used is a matter that must be decided in every location. In general, a location should not be begun with an attempt to limit arbitrarily the maximum degree of curve to any definite figure, but rather, the degree of each curve, where difficulty in obtaining the desired degree is encountered, should be determined for each case on its own merits.

As shown in the preceding article, the total effect on maintenance expenses is largely independent of the degree of curve for any given central angle, hence, the cost of conducting transportation is the only class of operating expenses that is likely to be affected by the degree of curve. The chief considerations in the choice of degree in this connection are (1) the highest speed of the trains to be operated over the line and (2) the diversity of the traffic carried. With fast passenger and slow freight trains passing over the same line, the conditions for unbalanced superelevation will be maximum. Suppose the freight trains pass a curve at 20 miles per hour and the passenger at 50, the former would need $0.26D$ in. of superelevation and the latter $1.65D$ ins., or a difference of $1.4D$ ins. For a 6° curve, assuming an allowable unbalanced superelevation of 3 ins., the superelevation for the passenger train would be $0.26\times6+3=4.56$ ins., if the freight service were allowed to govern. A superelevation of 4.56 ins. would correspond to a speed of 33 miles per hour. Reducing the velocity of a 750-ton passenger train from 50 to 33 miles per hour would mean a loss of $0.003511(50^2=33^2)\times750=37{,}500$ ft.-tons of energy. Assuming 5 lbs. of coal costing \$3 per ton to produce 1000 ft.-tons, this would mean $37.5\times0.0075=\$0.28$. Wear on brake shoes and rigging would probably amount to \$0.05 more and the coal for applying the brakes to \$0.01, making a total of \$0.36 for the cost of slowing down such a train on account of this curve. For one passenger each way per day, this would amount to $\$0.36\times365\times2=\$262.80$ per year. Capitalized at 6 per cent, this sum would mean an investment of \$4380. From Fig. 45, it is seen that the passenger train might pass a 4° 30′ curve with a superelevation of 4 56 ins. at 50 miles per hour without slackening speed. This reasoning would indicate that the sum of $4380 might be justifiably spent for each round-trip passenger train of the character assumed in order to reduce the 6° curve to 4° 30′.

The lost time due to slackened speed would probably be made up, hence, the lost energy would represent about the only source of loss to be considered. For freight trains, it is pretty well established that for any given central angle the cost of operation over a curve is practically independent of the degree within ordinary limits; hence, for railroads that are essentially freight lines, with perhaps one slow passenger train each way per day, it would seem impossible to justify any considerable expenditure in order to reduce the degree of curve below that fixed by the character of the rolling stock.

PART C

SPECIAL PROBLEMS IN RAILWAY LOCATION

CHAPTER XVIII

LINE CHANGES AND GRADE REDUCTION

Introduction. As recited in a previous chapter, the railroads of the United States to a very great extent were built piecemeal as small independent rural enterprises and were to a great extent improperly designed and do not adequately serve the needs of the traffic they are now required to carry for one or more of several reasons:

(*a*) They were located by county surveyors or others who had very little skill even in the art of surveying and certainly possessed no conception of the larger economic phases of location.

(*b*) Since their first location, these small local roads have been interconnected and joined to longer and stronger railroads to form great systems. In this way, some of the small roads have been made important links in such systems and are required to carry a traffic for which they were not designed, if, indeed, they were ever designed for any particular traffic conditions.

(*c*) Sources of traffic have changed in such a way as to throw heavier traffic over formerly unimportant lines. Agricultural regions that were formerly waste or grazing lands have become very productive. The development of coal mining and of manufacturing industries has frequently brought unexpected traffic to a railroad.

(*d*) The building of connecting lines that result in a new routing of traffic has caused the existing plant to become inadequate in several instances.

For these and other reasons it frequently becomes desirable to revise the alignment, or the grades, or both, over a given stretch of railroad in order to meet economically the newly imposed conditions of traffic. In certain respects, line revision differs from new location and it is deemed desirable to call attention to these differences and to other matters that are more or less peculiar to this sort of work in a separate chapter. Line improvement and grade reduction are so commonly undertaken together and are otherwise so closely related that it is impracticable to treat the two subjects separately.

It is very important that sufficient study be devoted to any proposed improvement to ascertain as accurately as possible the effect of such proposed changes. "Penny wise and pound foolish" is the policy that stints the expenditure for such studies when they are to control the expenditure of thousands, if not millions, of dollars. The primary aim of an improvement is to decrease the operating expenses, and in some instances to increase operating revenues, and the conditions should be studied in sufficient detail that the effect of the improvement can be predicted within a comparatively small percentage of accuracy. Moreover, the investigation should not be made piecemeal, but rather a comprehensive study should be made of the relation of the proposed improvement to any possible future improvement elsewhere along the line.

Naturally those stretches of railroad consisting of long gradients, as in passing over mountain ranges, are not subject to radical improvement in line and grade as a general rule, but railroads traversing undulating territory are most susceptible of such improvement.

Accounting. While at first it may seem extraneous to the engineer's problem to consider the accounting system involved in any improvement, as a matter of fact it is very important that the engineer keep in mind the essential features of the accounts to which the expenditures for improvements are charged. The Interstate Commerce Commission has formulated a uniform accounting system that is followed by all railways subject to its jurisdiction, and a part of this system provides for "Additions and Betterments," as mentioned on p. 95.

Although much of the property value of a railroad consists of intangible values, such as rights, franchises, etc., yet the physical properties constitute the only items that can be enumerated as accounts to which debits and credits can be charged in terms of universal usage. The physical property of a railroad which is listed as assets constitutes the fixed plant. The fixed plant is built supposedly at one time from the sale of securities and is assumed to represent a definite whole, and when the construction account is closed, it is usually not reopened, except under extraordinary circumstances. This fixed plant is supposed to be maintained at its original state by replacements, and from time to time improvements are made that in reality augment the fixed plant. For example, where 75-lb. rail is replaced with 90-lb. rail, there is a distinct betterment in the existing plant, which should be added to the total investment. The distinction between these terms is made clear by Mr. Walter G. Berg,* as follows:

"The term 'improvement' should represent all expenses which create a specific, permanent physical improvement, tending to increase the value of the railway property as a whole, in the form of a betterment or an addition to the property, subdivided into two groups, according to the following rules:

"'Betterments' to consist of any permanent betterments to the existing property and facilities, constituting an actual, distinct, positive, permanent, physical improvement, tending to increase the value of the railway property as a whole; the charge to cover in all cases only the difference in costs of the new improved structure or facility and estimated cost of replacing the old unimproved structure or facility. The term 'betterments' to apply in general to work such as replacing bridges with a more permanent character of materials, strengthening bridges for increased loading, rebuilding buildings, structures, auxiliary appliances and facilities of various kinds on a larger scale and with a better class of materials, increase of track mileage due to rearrangement and remodeling of existing yards and track layouts, stone ballasting, etc., provided the work in question does not consist merely of extensive remodeling and changing of existing facilities, producing no visible extension or important enlargement of such facilities.

"'Additions' to consist of any permanent addition to the existing property and facilities, constituting a distinct, separate, new, permanent, physical improvement, tending to increase the value of the railroad property as a whole, such as a new roadbed, tracks, bridges, buildings, structures, or any auxiliary appliances and fixtures, etc.; provided such addition or improvement is not in the nature of repairing, renewing, replacing, changing, or remodeling any existing facility."

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* Proc. Am. Ry. Eng. Assn., 1904.

This is essentially the view of improvements adopted by the Interstate Commerce Commission and to provide for the items that come under this classification, the temporary or continuing account, "Additions and Betterments," is provided, which at the end of the fiscal year, or at other convenient times, is charged into the regular capital construction accounts of "Expenditures for Road and Equipment."

If an improvement is charged to Additions and Betterments, therefore, it is virtually a capital account charge, and would serve with other investment accounts as a basis of capital charges of interest or dividends, and has an entirely different aspect from that of charging it to operating expenses. In Case No. 21,* decided by the Interstate Commerce Commission, that body stated that changes in grade and alignment accomplished by constructing a cut-off and abandoning the existing line should be charged chiefly to operating expenses, the exact rule being as follows: "The difference between the cost of the new line and the cost of replacing in kind the line abandoned, exclusive of right of way, should be charged to account No. 5, 'Grade Revisions and Changes in Line,' as provided in the Classification of Expenditures for Additions and Betterments." The bulk of the expenditure for such a cut-off would naturally be involved in constructing the new line similar to the old, which amount would be charged to operating expenses, according to this decision. Where the major portion of the cost of a new cut-off must be thus charged to operating expenses, it is usually difficult to demonstrate that the proposed improvement will accomplish any decrease in operating expenses. Railway directors may be loath to make expenditures for line and grade revision where such expenditure must be paid for out of current expenses and not become a fixed investment and subject to interest and dividends on the same basis as the original investment.

The Interstate Commerce Commission classification of Additions and Betterments provides 35 accounts as follows:

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* Circular No. 12, Int. State Com. Commission.

A 1. Right of way and station grounds.
A 2. Real estate.
A 3. Widening cuts and fills.
A 4. Protection of banks and drainage.
A 5. Grade reductions and changes of line.
A 6. Tunnel improvements.
A 7. Bridges, trestles and culverts.
A 8. Increased weight of rail.
A 9. Improved frogs and switches.
A10. Track fastenings and appurtenances.
A11. Ballast.
A12. Additional main tracks.
A13. Sidings and spur tracks.
A14. Terminal yards.
A15. Fencing right of way.
A16. Improvement of crossings under or over grade.
A17. Elimination of grade crossings.
A18. Interlocking apparatus.
A19. Block and other signal apparatus.
A20. Telegraph and telephone lines.
A21. Station buildings and fixtures.
A22. Roadway machinery and tools.
A23. Shops, enginehouses and turntables.
A24. Shop machinery and tools.
A25. Water and fuel stations.
A26. Grain elevators and storage warehouses.
A27. Dock and wharf property.
A28. Electric light and power plants.
A29. Electric power transmission.
A30. Gas producing plants.
A31. Snow and sand fences and snow sheds.
A32. Reconstruction of road purchased.
A33. Equipment.
A34. Interest and commissions.
A35. Other additions and betterments.

Reducing Curvature. In a previous chapter the cost of curvature and the economics of minimizing the curvature in railway location were discussed. The problem as related to line revision differs from that involved in new location in that in the former case the amount and character of the traffic are not matters of conjecture, but are capable of exact determination from the traffic records of the railroad. In some instances, however, the improvement may increase the amount of traffic somewhat by affording more attractive shipping facilities. The principles involved in determining the economic amount and degree of curvature for line revision are the same as before explained and need not be further discussed in this connection.

Spiraling Curves. The early railroads were laid out using circular curves without easements to join the tangents, and these were later eased off by the trackmen by throwing the P. C. inward. This practice, however, almost invariably made the curves sharp at the junction of the improvised easement with the simple curve and caused hard riding of the engines. The author has spiraled 4° and 4° 30′ curves that had been treated in this manner which at the junction of the trackman's "easement" and the circular curve exceeded 20° curve for 25 to 50 ft. He well remembers the disparaging statement of an experienced engineer with whom he was associated in his early professional life, to the effect that a section foreman with a good eye could run a better easement curve than a transitman could with an instrument, a statement that indicated ignorance of the transition spiral, for the merits of the easement spiral have been well demonstrated.

In spiraling curves on track realignment, usually no records are available as to the elements of the curve or as to the location of the P. C. of the curve, and the engineer must rely entirely upon his own observations made in the field. A somewhat more rapid rate of attaining superelevation than indicated on p. 433 may be utilized to advantage in some cases by compromising between easy riding and cost of realignment. The object is ordinarily to choose a spiral that will require the track to be thrown a minimum distance in order that it may remain as near the middle of the roadbed as possible. There are two general methods of procedure for inserting spirals given by Prof. A. N. Talbot in his book on the Transition Spiral:

1. By adopting a larger degree for the circular curve and throwing the ends inward and the middle portion outward, thus affording the proper offset for the spiral. This method is used chiefly for comparatively short curves. In this method, the entire curve is shifted, and the available space on the roadbed, the intersection angle and the degree of curve will affect the character of spiral that can be obtained. In running in the

spiral, the results may be tested to advantage by plotting up the *inthrows* and the *outthrows* necessary to bring the track to the new alignment, the former being plotted on one side of a base line and the latter on the other, the distance along the track being taken as abscissas. If as much of the resulting graph lies on one side as on the other, the throws balance and the track can easily be thrown to place.

2. By compounding the ends of the existing curve with curves of shorter radius, thus obtaining the necessary offset for the spiral. This method is applicable especially to curves of considerable length. The distance that the P. C. will have to be thrown in will be one-half the offset, and since this distance represents the ordinate between the original and the sharper curves, the central angle necessary to give this required distance can be readily calculated.

For the most convenient method of procedure in spiraling existing curves, the reader is referred to Prof. Talbot's book on "The Transition Spiral."

Cut-offs. While many railroad alignments may be open to improvement by spiraling and otherwise realigning the track on the existing roadbed, or with but little change in the position of the center line, radical improvement usually comes from a more extensive shifting of the location involving a bolder attacking of the topography than was justified in the original location. This is accomplished by means of what is commonly termed a *cut-off*, which, by means of going a more direct route and by the use of tunnels, extensive bridging, heavy grading, or other device, usually shortens the total distance and at the same time decreases the ruling gradient and eliminates curvature.

While the conditions of any one cut-off project are seldom very similar to those of another, yet certain general features may be mentioned that are worthy of consideration in this connection. From the general character of the construction involved, four types of cut-offs for improving alignment and grade may be recognized, viz.:

1. Tunnel cut-offs.
2. Summit cut-offs.
3. Bridge cut-offs.
4. Cross drainage cut-offs.

These will be briefly described and illustrated with examples.

Tunnel Cut-offs. This type of cut-off may be undertaken to improve a line that makes a long detour around a ridge or range of hills, by cutting through the ridge by means of a tunnel. It may happen, of course, that a proposed shortening of the line by this method will unduly increase the ruling gradient where the detour has been made in surmounting the summit, in which case all advantage from shorter distance and diminished curvature would be lost, and hence the undertaking would not be permissible.

Fig. 46 illustrates an example of tunnel cut-off that was constructed on the Allegheny division of the Pennsylvania R. R.* about 30 miles north of Pittsburg. The original road was constructed about the middle of the last century, when the necessity for cheaper construction resulted in a location following closely the windings of the river. The traffic at the time of reconstruction consisted of five passenger trains and an average of 25 freight trains each way per day. The East Brady tunnel shortens the line 5.35 miles and eliminates 364 degrees of curvature. The middle portion of the tunnel consists of 2393 ft. of 3° 16′ curve, and the end portions of 4° curves, one 439 and the other 560 ft. long.

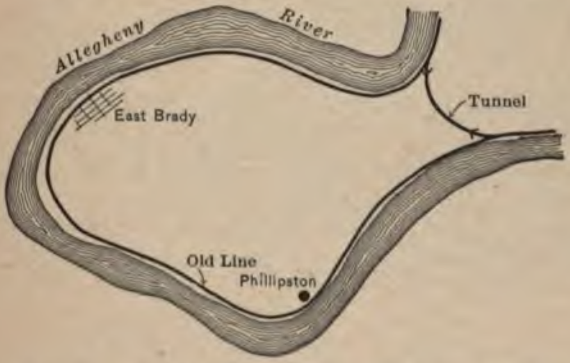

FIG. 46.—Tunnel Cut-off on the Pennsylvania R.R.

Fig. 47† further illustrates this class of line revision, being a cut-off that was made on the Kanawha and Michigan R. R.

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* *Railway Age Gazette*, Sept. 10, 1915.

† *Engineering News*, Jan. 7, 1909.

near Langsville, Ohio, which was rendered desirable because of the increased traffic over the road, due especially to heavy coal haulage. The original line contained curves as sharp as 8° 43′; the revised alignment has a maximum of 3° curve and a maximum gradient against northbound traffic of 0.3 per cent and 0.5 per cent against southbound traffic.

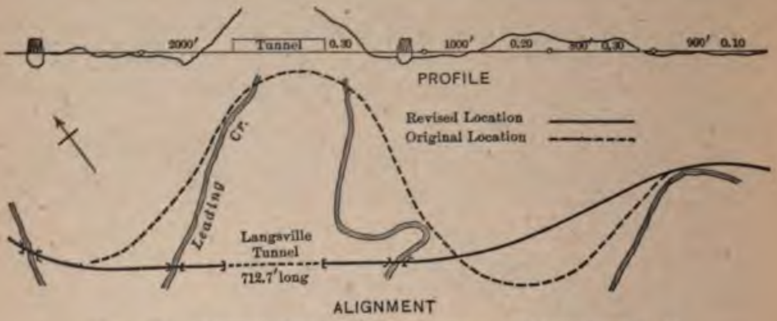

FIG. 47.—Tunnel Cut-off on Kanawha & Michigan R. R.

Fig. 48 is a sketch of the Magnolia cut-off of the Baltimore and Ohio R. R., which included some very heavy earthwork and cost about $6,000,000, or $500,000 per mile. It saves 5.95 miles in distance and 877 degrees of curvature; reduces maximum gradient against the heavy eastbound traffic from 0.5 to 0.1 per cent, eliminates one helper grade 2.8 miles long, thereby

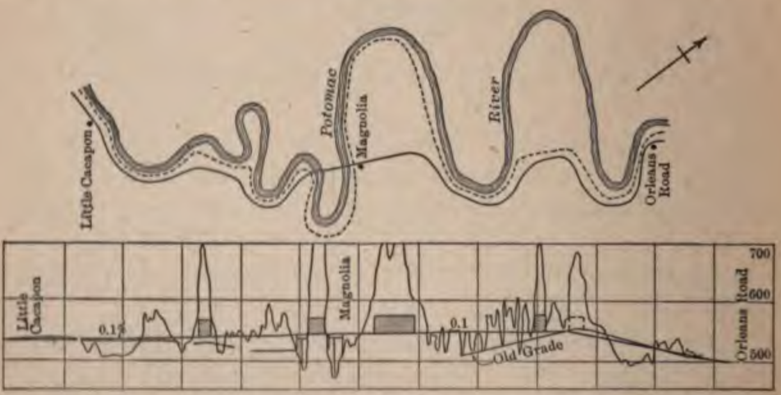

FIG. 48.—Magnolia Cut-off on the Baltimore & Ohio R. R.

releasing two pusher engines. Four tunnels and two additional river crossings were required.

Summit Cut-offs. Sometimes in crossing a ridge of hills or mountains, a slight detour with a tunnel or deep cut through the crest of the range may shorten the line and at the same time decrease the gradient. Fig. 49 is a map of the Rogers Pass realignment on the Canadian Pacific Railway, where a detour up Beaver River and a tunnel 26,400 ft. long greatly reduced the length of the 2.2 per cent grade and at the same time avoided the extended use of snow sheds. Fig. 50 shows the summit cut-off of the Delaware, Lackawanna and Western R. R. from Halsted to Clark's Summit. In searching for the best route in this case, over 300 miles of preliminary lines were run, the surveys extending over a period of about three years. The improvement involved cuts as deep as 114 and 115 ft., and fills as high as 120 and 142 ft. at maximum points. The Tunkhannock viaduct of reinforced concrete is about one-half mile long, and consists of ten 180-ft. and two 100-ft. arches, and

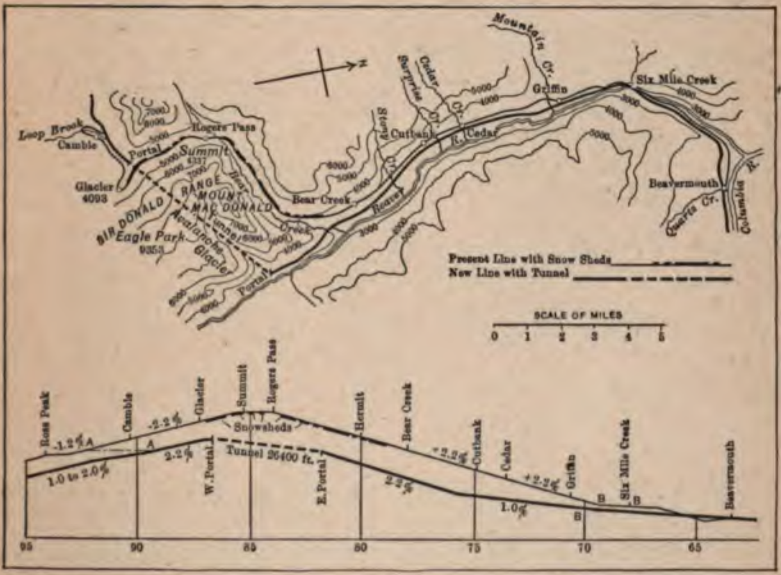

FIG. 49.—Rogers Pass Summit Cut-off on Canadian Pacific Ry.

has a maximum height of 240 ft. The results accomplished are as follows:

	Old.	New.	Difference.
Length of line, miles	43.2	39.6	3.6
Maximum grade, E. B., per cent	1.23	0.68	0.55
W. B., per cent	0.52	0.24	0.28
Rise and fall, feet	553	226	327
Total curvature, degrees	3940	1500	2440
Maximum degree curve	6° 22′	3° 00′	3° 22′

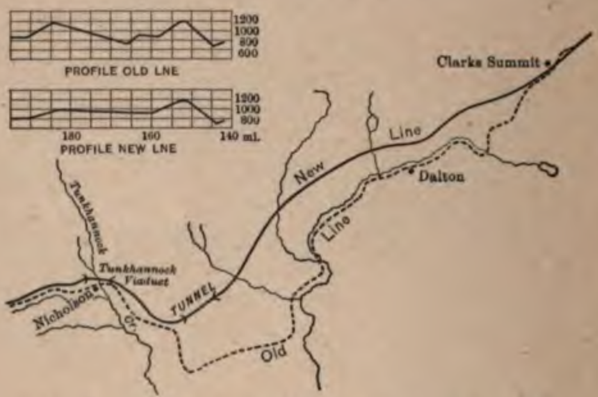

FIG. 50.—Summit Cut-off on the Lackawanna R.R.

Bridge Cut-offs. This class of line revision is possible chiefly in the case of a location following the sinuosities of a stream in a rolling country, and consists of cutting directly across the bends of the river and the intervening hills, using bridges for crossing the stream wherever necessary. Fig. 51 shows a revision in the alignment of the Pennsylvania R. R. by which 4700 ft. of distance was saved, many sharp curves were avoided and 494 degrees total curvature eliminated. It involved four additional bridges across the Little Conemaugh River and some heavy earthwork grading, the deepest cuts being 105, 106 and 120 ft. deep.

Cross Drainage Cut-offs. Most railways have been located originally to follow the natural drainage pretty closely, either on the water sheds or in the valleys. Many, however, have been constructed across the drainage and in most cases were compelled by the demands of economy to follow the undulations of the topography traversed and to keep along the grade contour for the most part, winding in and out of valleys and around the ends of ridges. This defect is being remedied now on several of such lines by abandoning the sinuosities of the existing line and boldly striking across the drainage, constructing whatever fills and cuts that are rendered necessary. The following examples illustrate this type of improvement:

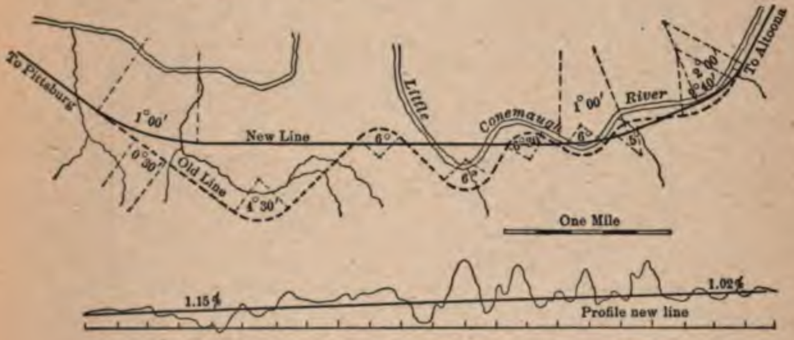

FIG. 51.—Bridge Cut-off on the Pennsylvania R. R.

On the Erie R. R., on the line between Cambridge Springs and Union City, a portion of a longer relocation, a marked grade reduction and general line improvement was secured by a cross drainage cut-off. The old eastbound grade was 1.0 per cent and the westbound grade was 0.9 per cent. These were reduced to 0.2 and 0.3 per cent respectively. The old eastbound gradient limited the rating of a 169-ton consolidation locomotive to 1400 tons, but the new gradient allows this to be increased to 4300 tons; in a like manner, the rating on westbound traffic was increased from 1600 to 4300 tons.

A similar project is exemplified in the relocation of the Chicago, Milwaukee and St. Paul R. R. across Iowa, by which the ruling gradients of 0.67 and 1.0 per cent were reduced to 0.5 on two divisions and 0.66 per cent on the middle division. Over 1000 ft. of rise and fall were eliminated; 4° and 6° curves were reduced to 1° 30′ curves; 3230 degrees of central angle of curvature were avoided; and the length of the line reduced from 275.7 miles to 271.0 miles.

The traffic consists of about 8 passenger trains each way per day with extra sections 3 or 4 days per week, and about 15 freight trains, carrying 15,000 tons, each way per day. The divisions involved constitute a portion of the main line from Chicago to Omaha, and in addition to the local traffic along the line, carries a through passenger service and through freight service in connection with the Union Pacific R. R., with which it connects at Omaha and Council Bluffs. On the old grades, the heaviest 275,000-lb. Mikado engine with a tractive effort of 50,600 lbs. could pull about 2100 tons, and under the new grade conditions it can pull about 2950 tons. The total cost of the improvement, including double tracking, was about $18,000,000. Fig. 52 shows the character of the work at the crossing of the Des Moines River.

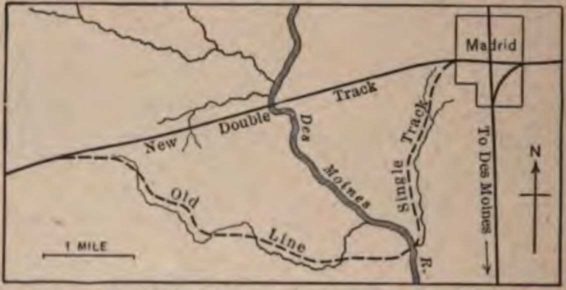

FIG. 52.—Cut-off on C., M. & St. P. Ry. near Des Moines, Iowa.

The results of this work are summarized below:

GRADE REVISION, C., M. & ST. P. RY.

	Districts.					
	First.	Second.	Third.	Fourth.	Fifth.	Total.
Length of line, miles						
Old	38.9	76.2	81.5	47.3	31.8	275.7
New	38.1	76.2	80.5	45.1	31.1	271.0
Difference	0.8	0.0	1.0	2.2	0.7	4.7
Saving in rise and fall, ft.	115	14	175	365	422	1031
Maximum grades, %						
Old	0.776	0.776	1.0	1.0	1.0	
New	0.5	0.5	0.66	0.65	0.5	
Difference	0.276	0.276	0.34	0.35	0.5	
Curvature, maximum						
Old	4°	4°, 6°	6°	6°, 4°	4°	
New	1° 30′	1° 30′, 2°	2°	2°, 1° 30′	1° 30′	
Difference	2° 30′	2° 30′, 4°	4°	4°, 2° 30′	2° 30′	
Central angle						
Old	1091° 17′	960° 56′	1241°	964° 37′	1762°	6020° 10′
New	749° 38′	801° 41′	569°	156° 35′	514°	2790° 54′
Difference	342° 39′	159° 15′	672°	808° 02′	1248°	3230° 16′
Total cost	$2,000,000	$2,671,000	$3,750,000	$7,000,000	$2,750,000	$18,171,000

Fig. 53* is a map of the cut-off on the Norfolk and Western R. R. between Pamplin and Burkeville, a distance of 37 miles, by which the last pusher grade on the line was eliminated and the ruling gradient reduced to 0.1 per cent against the heavy eastbound traffic. It avoids the drop to the Appomattox River and follows the water shed through rather heavy rolling country. The new line is to be used as a single track for eastbound coal business, the old line being retained for passenger traffic.

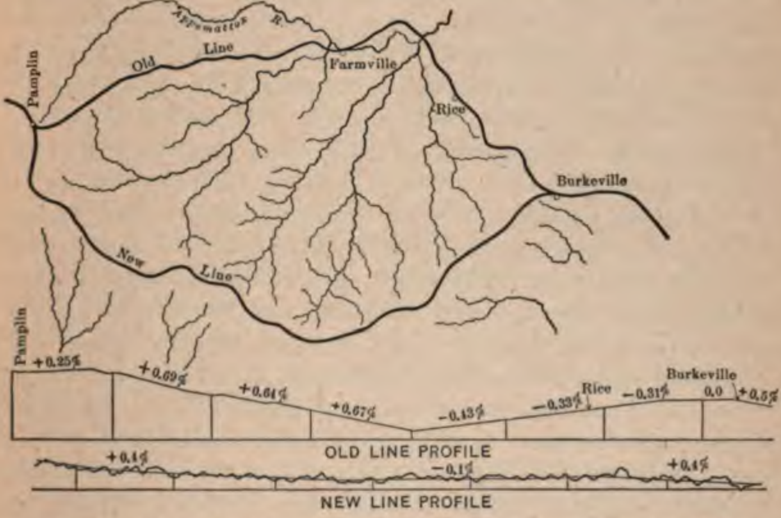

FIG. 53.—Cross Drainage Cut-off on the Norfolk and Western Ry.

The Economical Grade. The economical grade is the grade up which the traffic can be hauled at a minimum total cost so far as the cost is influenced by the grade. This minimum cost will be secured when the fixed charges on the investment used in reducing the grade and the operating expenses are made the least possible. See Fig. 101 for graphical illustration of this principle. A great deal of difference of opinion exists as to when the economical grade is reached for any given conditions. When the grade is very low in rate, it is necessary to load the trains very heavy in order to realize the advantage of the low gradient, hence the time of travel of the freight trains is increased, owing to the slower speed over the whole line, and with the slower speed, the operating expenses increase. The grade probably cannot be reduced economically to such an extent that the economic speed cannot be maintained between stations (see Chapter XII). Moreover, the relative speeds on the ruling grade and on the level should be taken into consideration. The limit of reduction of ruling grade should be such that the locomotive will be able to haul the heaviest train up this grade at the minimum permissible speed that it can haul on the level at the maximum permissible speed. For example, if the locomotives used can haul their trains at a speed of 10 M.P.H. up the ruling grade of 1.0 per cent and at 40 M.P.H. on the level when the maximum permissible speed is only 30 M.P.H., then the grade should be reduced so that the load may be increased to the capacity of the locomotive at 30 M.P.H. on the level. It is obvious from the above that the economical rate of grade depends upon the characteristics of the motive power and on the average weight of cars hauled. The general practice, even on very busy lines, has been to accept a gradient of not below 0.2 to 0.4 per cent against heavy traffic in easy country and 0.4 to 0.6 per cent in more difficult regions. It is frequently assumed that a locomotive will haul up a 0.3 per cent grade any train that it will start on the level. Assuming a train resistance of 6 lbs. per ton, the total resistance on this grade would be 12 lbs. per ton, or about equal to starting resistance. While actual starting resistance of a single car when the bearings are cold may be even greater than this figure, owing to the advantage obtained from the slack in the train by means of which the front cars are set in motion when those behind are being started, starting friction may be taken as low as 12 lbs., and in some cases as low as 10 lbs., making the proper grade 0.2 per cent. Of course, each case has to be decided on its merits in accordance with the traffic and topographic conditions encountered.

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* *Railway Age Gazette*, April 19, 1916.

Time Element in Grade Reduction. The time of operation over grades and the time required for trains to pass between grades are important considerations. Frequently a rearrangement of sidings on a single-track road with special reference to the actual time schedule of trains will materially improve operating conditions. As intimated in a previous paragraph, the heavy train loads that are essential to the realization of the full benefit of low grades may cause the average speed to be so low, or in other words, the total time over the division to be so great as to nullify the advantages to a large extent of the low gradients. In an article in the Proceedings of the American Railway Engineering Association, 1908, Mr. A. K. Shurtleff points out the importance of considering time as an element in grade reduction problems. Grades are reduced with a view to increasing the tonnage rating of locomotives. If the loads are increased, the speed will necessarily be slower than before over the level or light-grade portions of the track, provided no heavier power is employed, and as a consequence the total running time be increased, and if the operating conditions will not permit such an increase in time, a negative advantage may result from the decrease in grade. The lower grade line, of course, would make the use of heavier power economical. Mr. Shurtleff estimates the time required for a train with maximum loading for a 0.5 per cent grade and one loaded for a 0.3 per cent grade, and shows that under rather extreme conditions the time required to pass over the division of 120 miles length might be 1.75 hours longer for the second train than for the first. Such a disadvantage would largely offset the advantages of the heavier train load secured by the lower gradient.

Electrification vs. Grade Reduction. Owing to the heavy investment or initial cost of installation in electrification, it has not been proved economical over ordinary roads with comparatively light traffic and light gradients, but where the grades are heavy and the traffic dense, so that the capacity of the power stations can be utilized at approximately a constant rate all the time, electrification may be very properly considered as an alternative of grade reduction in order to cheapen the cost of transportation. The two schemes have similar characteristics in respect to the economics of the question, namely, the fixed charges are increased in order that the operating expenses may be decreased. Electric locomotives cost about the same or somewhat more than steam locomotives, while the power plant, the substations, and the transmission lines add very greatly to the investment costs. The advantages of electric operation lie in the economy of fuel and the increased capacity of the power units, due to greater speed, fewer delays, and longer runs without repairs. The ability to recover a portion of power lost on down grades by generating current back into the line may also effect some economy in operation. Heavy traffic is the condition that may justify either grade reduction or electrification; hence, in a sense, they may be considered as alternatives in making the desired improvement.

One of the most interesting electrification projects made over heavy-grade engine districts is the electrification of the Chicago, Milwaukee and St. Paul R. R. between Harlowtown, Montana, and Avery, Idaho, a distance of 440 miles. The traffic is not extremely heavy, but the proximity to cheap electric power (.536 cent per kilowatt hour) from hydro-electric plants readily pointed to the possible economies by means of electrification, and in addition, material grade reduction was impracticable. The stretch of line involved consists of four engine districts and passes over three mountain ranges. The profile in Fig. 54 shows the grades encountered. The electric locomotives selected are of the direct-current type capable of hauling 800-ton passenger trains up 1.0 per cent grades at 35 M.P.H., and the freight locomotives are capable of hauling 2500-ton trains up the same grade at 16 M.P.H. Over the 1.7 and the 2.0 per cent grades a similar locomotive will be used as a pusher. The pusher locomotive will also accompany the train down the grades to assist in braking, thereby generating additional energy, about 50 per cent of the total energy due to the grades being recoverable in this manner. Inasmuch as only 20,000 kilowatts are available from the power plants, care on the part of the train dispatcher must be exercised to avoid having all the trains on the up grade at the same time, else the

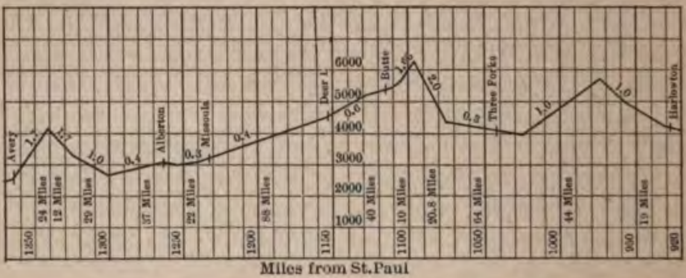

Fig. 54.—Profile of Electrified Line, C., M. & St. P. Ry.

power available will prove insufficient. By properly scheduling the trains, however, some can be descending grades while others are ascending, thereby making a more nearly constant draft on the power. Ultimately the intermediate division terminals are to be practically abandoned and the entire length operated as one district.

CHAPTER XIX

ELIMINATION OF GRADE CROSSINGS

Introduction. In recent years there has been a growing demand for the elimination of grade crossings, both railway and highway crossings, and in rural districts as well as in the cities. The agitation has come from many who have had little appreciation of the enormous costs involved in such an undertaking, and because of this lack of understanding some have urged legislation looking to the abolishing of all grade crossings. As a matter of fact, it is difficult to justify, from an economical point of view, the elimination of any grade crossing, except, perhaps, at the very busiest points. In ten years, the Pennsylvania Railroad expended $66,000,000 in the elimination of a little over 1000 crossings, the cost averaging about $65,000 each. There are about 13,000 grade crossings on this road, and if they were abolished at, say, $50,000 each, the total cost would be $650,000,000. It would be necessary for the gross earnings of the system to be doubled in order to pay the fixed charges on this sum, and not even the most enthusiastic would venture to say the elimination of these grade crossings would materially increase the revenues. Moreover, as the country develops, the number of grade crossings increases and consequently this expense will go on indefinitely.

The general scope of grade crossing elimination may be outlined as follows:

A. Highway crossings:
    1. In rural districts:
        a. Farm crossings.
        b. Public highway crossings.
    2. In cities:
        a. Street elevation.
        b. Track elevation.
        c. Track depression.

B. Railway crossings:
  1. Electric interurban.
  2. Street railway.
  3. Steam railway.

The total cost of abolishing a grade crossing includes not only the actual cost of construction, but also the necessary expenditure occasioned by damages to adjacent property and litigation expenses connected therewith. Grade separation in cities most frequently results from the action of the city council requiring the same and not from a study of the actual needs of the case. However, each case should receive a careful study as to traffic conditions and the cost of separation treated accordingly.

For a résumé of state laws pertaining to grade crossings, the reader is referred to the Proceedings of the American Railway Engineering Association (Am. Ry. Eng. and Main. of Way Assn.), Vol. II.

Economics of Grade Separation. So long as a highway crosses a railroad at grade, the railroad is put to some expense to prevent accidents occurring at the crossing and the public is put to some inconvenience in preventing accidents, and both suffer when an accident occurs. The interests are therefore mutual, and, wherever practicable, the expense in securing safety should be shared by the public and the railroad. So long as the protection consists of a crossing sign, a bell, a moving signal, or a watchman, the railroad invariably bears the expense, but when a program of grade separation in a city is undertaken, the expense is frequently shared by the public, as it should be.

The advantages of grade separation are chiefly involved in the removal of the element of danger to those crossing the railroad, although the removal of danger to the public reacts to the benefit of the railroad as well. The separation of grades avoids the maintenance of crossing signs, signals or watchmen, and the cost of slow orders or stops at busy crossings. On the other hand, it involves the cost of building and maintaining the structure required for the over or under crossing. The economic advantages of a grade separation can seldom be shown to justify the undertaking, but where the loss of human life is likely to result frequently from a grade crossing, considerations of humanity require that the grades be separated.

Crossing Accidents. Highway crossings are a prolific source of accidents to the public. Table XLVII shows that about three-fourths of the persons other than employees, passengers, or trespassers met their deaths at highway crossings. As will be shown in a succeeding paragraph, the persons crossing a railroad are usually responsible for the accident through their own negligence, but regardless of this fact, all should be done that is possible to prevent such accidents, and grade separation is about the only sure remedy. By the elevation of tracks in Chicago, the total number of accidents from crossings was reduced about 80 per cent.

TABLE XLVII

ACCIDENTS TO OTHERS THAN EMPLOYEES

1909

Kind of Accidents.	Passengers.		OTHER PERSONS.					
			Trespassing.		Not trespas'g.		Total.	
	Killed.	Inj'd.	Killed.	Inj'd.	Killed.	Inj'd.	Killed.	Inj'd.
Collisions	69	2379	13	49	25	447	28	496
Derailments	17	2426	32	69	6	287	38	356
Parting of trains	...	47	3	3	...	13	3	16
Loco. or cars breaking	...	2	...	1	1	4	1	5
Falling from train	37	425	413	732	13	72	426	804
Jumping on or off trains	81	1503	445	1688	11	120	456	1803
Struck by trains:								
At highway crossings	2	3	112	211	621	1619	733	1830
At stations	30	67	365	334	66	183	431	517
At other points	1	12	3371	2037	79	143	3459	2180
Other causes	12	2715	190	633	47	1030	237	1665
Totals	249	9579	4944	5759	869	3918	5313	9677

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Highway Crossings. The amount of traffic on the highway that justifies the elimination of a grade crossing with a railroad depends upon circumstances to a great extent, chiefly perhaps upon ease of vision by the occupants of vehicles in approaching the crossing. High banks occurring where a highway crosses a railway in a deep cut may make a particular crossing exceedingly dangerous even with few vehicles crossing per day and few trains on the railroad. Cars standing on a siding on either side of a crossing, a curved track or other cause of obstruction to view may have a like effect. Except on drives with an unusually heavy traffic where the line of vision is unobstructed for 400 or 500 yards each way from the crossing, grade separation is seldom imperative for country highways.

Grade crossings are eliminated by carrying the highway either over or under the railway, or, as commonly termed, by an over or an under crossing. Which of these methods is preferable for any given location depends upon the conditions of topography usually. If the railroad is on an embankment, and particularly if a bridge over a natural drainage channel is near to which the highway may be led without too great inconvenience, the under crossing will be preferable. If, however, the crossing occurs at a deep cut or on the level, the overhead crossing by means of a bridge will be found the more economical and satisfactory.

Street Crossings. With the more congested conditions that are to be found on city streets, especially where street-car tracks are involved, the need for grade separation becomes more pressing. Safety devices, such as signals and slow orders, may be installed, but while they may insure safety, they impede traffic movement either on the highway or on the railway or on both. The separation of grades may involve an overhead bridge or a subway at a few of the most important street crossings, or it may require a general scheme of track elevation or depression, as in the case of large cities.

Traffic that Justifies Grade Separation. The determination of the amount or density of traffic that justifies separation of grades obviously depends on the risk of a train colliding with a vehicle on the highway, and this risk is dependent upon the frequency of trains and the frequency of the passage of vehicles on the highway. If the time of passage of a train is t minutes and the time of passage of a vehicle is t' minutes, N the average number of trains and N' the average number of vehicles per hour, then the chance or probability that any particular vehicle will collide with a train is $\frac{N'tt'}{(60)^2}$ (60 being the number of minutes in an hour), and the chance or probability that *any* vehicle will collide with a train is $\frac{NN'tt'}{(60)^2}$.

To apply this principle, it is necessary to assume some relation between pedestrians and vehicles and between street cars and vehicles in regard to the relative danger of accident, involving the relative time of passage and the number of persons included. Considering the length of time of passage, the number of persons endangered, the relative precautions taken and the relative agility of the units of traffic on the highway, the following ratios may be reasonably assumed:

5 pedestrians = one vehicle
1 street car = three vehicles.

Assuming $t=t'=\frac{1}{12}$ minute, grade crossings have been eliminated with apparent justification when the chance of accident became about 1:200, and from a study of several specific instances; this ratio might be taken as a measure or index of the hazard that justifies the elimination of a grade crossing, the conditions being for the average twelve hours of heaviest traffic on a normal day.

Accident statistics do not, of course, show anything like this percentage of accidents, but that they do not is due to the use of warnings and to the watchfulness of persons using the crossing. The " hazard " is in reality the mathematical chance that a vehicle and a train might meet at the crossing if both were operated without the control of human intelligence.

In general, somewhere near 8 per cent of the total persons killed or injured by steam and interurban railways in the United States receive their injury at a crossing, and about 3 per cent for street railways. On the average, there is a grade crossing for about every half mile of railway in the United States, or about 450,000 highway grade crossings. If on an average, 10 persons crossed each of these crossings per hour, there would be $450{,}000 \times 85{,}600 = 3{,}852{,}000{,}000$ persons crossing once per year. There are on the average about 900 to 1000 persons killed per year, hence, the actual hazard is about 1:4,000,000. Or in other words, one might cross a railroad 4,000,000 times before the chances would be even that he would be killed. The chance of being injured is approximately 10 times as great. The difference between the theoretical hazard and the actual hazard results from the exercise of human intelligence.

In the Proceedings of the American Railway Engineering Association, 1914, Mr. C. E. Smith, Asst. Chf. Engr. Missouri Pacific R. R., records the results of some observations of traffic

TABLE XLVIII

TRAFFIC AT HIGHWAY CROSSINGS

Crossing.	Record.		Average Traffic per Hour-Number.				Hazard $t=t'=5$ sec.	Action.
	Time.	No. Hours.	Pedestrians.	Vehicles.	Street Cars.	Trains.		
Tower Grove, St. Louis	6 A.M.–12 P.M.	18	330	137	22	13	1 : 148	Grades separated.
Central Square, Lynn, Mass	....	17	1240	124	21	10	1 : 117	"
Oak St., Taunton, Mass.	....	13	210	38	9	16	1 : 303	"
Pleasant St., Malden, Mass.	....	12	......	69	43	8	1 : 328	"
State St., Schenectady	....	24	2613	81	31	12	1 : 76	"
Union St., Schenectady	....	24	225	43	.....	13	1 : 455	"
W. Ave., Lynn, Mass	6 A.M.–11 P.M.	17	380	82	15	2	1 : 1278	Grades not specified.
West St., Syracuse, N. Y.	6 A.M.– 8 P.M.	14	343	155	.....	25	1 : 93	"
3d St., Niagara Falls, N. Y	7 A.M.– 8 P.M.	13	657	135	.....	11	1 : 178	"
Mass. Ave., Cambridge	....	24	53	82	76	1	1 : 1620	"
Mill St., Lacrosse, Wis	7 A.M.– 6 P.M.	9	99	33	14	11	1 : 500	"
Kinzie St., Chicago	....	12	315	413	.....	9	1 : 126	"
106th St., Chicago	....	12	77	27	6	5	1 : 1728	"
Indianapolis Blvd., Chicago	....	12	63	29	12	3	1 : 2220	"
Center St., Ashtabula, O	....	12	138	67	11	3	1 : 1400	"
Chouteau Ave., St. Louis	....	17	140	93	48	9	1 : 216	"

conditions on certain crossings where grade separation was either undertaken or considered. These results are summarized below and the relative hazard on the above basis determined for each case given by Mr. Smith.

At the Tower Grove crossing, St. Louis, both the city and the railroad acknowledged the need of grade separation. The traffic for eighteen hours, from 6 A. M. to midnight, November 3, 1909, was as shown in Table XLVIII. This table also shows a number of instances where the traffic was considered sufficiently heavy to justify grade separation and a number of others where the grades were not separated, although the conditions were studied with a view to separation.

As might be expected, the density of traffic both on the highway and on the railway varies with the hour of the day. The street traffic is heaviest about six to eight o'clock in the morning and about five to seven in the evening, corresponding to the hours of going to and from work.

Delays to Traffic. Where slow orders or stop orders are in effect for a crossing, the trains may be delayed, but usually the delay is borne by the street traffic only. The total amount of delay depends obviously upon the density and character of the traffic. In the article by Mr. C. E. Smith, referred to above, some data are presented showing the loss of time to pedestrians, autos and other vehicles, and to street cars. These results are abstracted in Table XLIX.

TABLE XLIX

DELAY TO TRAFFIC AT STREET CROSSINGS

Crossings (St. Louis).	PEDESTRIANS.		HORSE VEHICLES.		AUTOMOBILES.		STREET CARS.	
	Per Cent Delayed of Total.	Average Delay, Seconds.	Per Cent Delayed of Total.	Average Delay, Seconds.	Per Cent Delayed of Total.	Average Delay, Seconds.	Per Cent Delayed of Total.	Average Delay, Seconds.
Kingshighway....	2.6	5.8	2.7	31.6	3.2	33		
Gravois Road....	0	......	0.7	40	0	......	2	34
Broadway.......	1.4	32	4	57	4	89	5.4	60
Ivory Ave.......	1.0	30	1.5	58	3.6	52		
Chouteau Ave...	3.0	18	8.0	52	......	......	13	60

These observations indicate that the delay to street traffic because of grade crossings is so small as to be almost negligible. Out of twenty-eight instances of fire department vehicles using fifteen crossings in seven days' observation, there was not one instance of delay. How much delay to traffic is allowable before the crossing should be eliminated cannot be stated, since the elimination of the crossing depends upon the danger involved and the cost of the undertaking. However, when 5 to 6 per cent of the traffic is being delayed thirty to sixty seconds, the conditions become very annoying and are the source of much complaint. The delays at crossings, in fact, usually excite more complaint than the attendant danger. Economically, the delays to traffic can scarcely be made to justify the expenditure for grade separation, unless the ill-will of the public be taken into consideration. Coupled with the danger of loss of life, however, the delays to street traffic and other disadvantages of grade crossings all go to make up a case favoring the separation of the grades.

Responsibility for Crossing Accidents. Legally, a railroad is responsible for a crossing accident only when it results from negligence on the part of its employees or from a failure to provide the proper and legal safeguards. As a matter of fact, most of the accidents that occur at crossings result from the negligence of the other party. In the paper by Mr. Smith, referred to above, some observations are presented to indicate the care exercised by persons at highway crossings to prevent accident. See Table L.

TABLE L

RESPONSIBILITY FOR CROSSING ACCIDENTS

Traffic.	Stopped and Looked both Directions, Per Cent.			Kept Moving and Looked.								
				Both Directions, Per Cent.			One Direction, Per Cent.			Straight Ahead, Per Cent.		
	K	B	C	K	B	C	K	B	C	K	B	C
Pedestrians	1	...	...	2	12	...	9	19	...	88	69	
Motorcycles and bicycles	...	...	...	1	...	...	2	...	...	97		
Teams	...	...	...	3	17	...	5	17	...	92	66	
Autos	...	5	...	1	13	...	8	16	...	91	66	
All traffic	0.0	0.0	0.0	2	13	35	7	18	7	91	69	58

K = Kingshighway, St. Louis. B = B. & O. Crossings in Ohio and Indiana.
C = California observations at San Francisco, Oakland, Sacramento.

This table shows that the vast majority of persons pay practically no attention to the possible danger at a crossing and less than one-tenth of 1 per cent take the trouble to "stop, look and listen," as the injunction so commonly reads on crossing signs. With a greater degree of caution on the part of the public, the safety of grade crossings would be greatly enhanced.

Apportionment of Cost of Grade Separation. It is to the interest of both the railway and the public to secure the safety of railway crossings, and since railways are quasi-public corporations, as has been stated previously, the public should in most cases share the expense of abolishing grade crossings. This recognition of joint interest and joint responsibility has been exemplified in most of the grade separation work that has occurred in the United States, as shown in Table LI.

TABLE LI

DISTRIBUTION OF EXPENSE OF GRADE SEPARATION

Place.	Railroad Per Cent.	City Per Cent.	Street Railway Per Cent.
Connecticut	50–75	25–50	..
Massachusetts	65	20	15
New York	50	50	
Ohio	50	50	
Vermont	65	35	
Atlanta, Ga.	Work over tracks.	Approaches and damages.	
Chicago	Construction	Damages	
Detroit	"	"	
Philadelphia	50	50	
Providence	66⅔	33⅓	
Kansas City	Remainder	½ of bridges used.	..
Scranton	66⅔	..	33⅓
Denver	33⅓	33⅓	33⅓
Little Rock	61	20	19
Wichita, Kan	33⅓	33⅓	33⅓

Track Elevation. When in the larger cities many grade crossings require elimination, a general scheme of grade separation is undertaken by means of *track elevation* or *track depression.* Track elevation consists of carrying the tracks on an embankment through the city blocks and by a viaduct over the streets. The work is always much complicated by the necessity of providing for the continuance of traffic, by the necessity for taking care of many city substructures, such as sewers, water and gas mains, etc., where the streets are depressed, and by the property damages that accrue. The structures involved in track elevation are mainly, (1) embankments, (2) retaining walls and (3) viaducts or bridges.

To attempt any extended discussion of the design of these classes of structures is entirely beyond the scope of the present treatise, and moreover, is entirely unnecessary owing to the fact that many books have been written specifically treating of these subjects.

The embankment is usually constructed by the process of building and filling in a trestle. The earthwork may be hauled from a considerable distance on trains and dumped by means of a Lidgerwood unloading plow. The traffic is shifted to one side of the right of way while the embankment on the other side is being constructed and then on to this fill while the fill is being placed on the former side. The trestle usually can be built entirely of timber, and as it is of a temporary nature, it can be constructed of low-grade material and usually entirely on top of the ground without the use of piling.

The retaining walls are built to hold the embankment at the sides of the right of way. They are usually of considerable height, with practically a vertical face, with a small portion of the footing projecting in front of the face of the wall, and they should be designed to carry a superimposed train load on the earth in addition to the earth itself. Reinforced-concrete walls, either of the cantilever or the counterfort type, are well adapted to this use.

The viaducts for carrying the tracks over the streets vary widely in type of construction. The older ones were plain plate girders, with either solid or open floors, resting on masonry abutments. Solid trough floor construction was next used, the floors being usually covered with concrete. At the present time, practice seems to have settled on some type of girder spans with steel trough floor construction or with concrete floors, steel girders masked with concrete, or else entirely reinforced concrete structures. The latter seems to fulfill the requirements of such a structure better perhaps than any other type. Viaducts for bridges over streets should possess the following peculiar characteristics in addition to the properties that should pertain to any bridge:

1. They should be sightly in appearance in order to detract as little as possible from the value of adjacent property, and to promote the general beauty of the city. This applies with special force to the structures over boulevards or pleasure drives.

2. They should be absolutely water-proof in order that the ballast of the roadbed may not hold water and let it drip on persons beneath. To this end also, the floors should be very completely drained in order to carry the water away as readily as possible.

3. They should be as noiseless as possible. Noise results from vibration, hence, open steel work or other type of construction that will vibrate intensely with the passage of trains should be avoided. Fig. 55 shows typical track elevation structure for crossing city streets.

Track elevation has the following advantages over track depression as a mode of separating grades:

1. Drainage of the track and roadbed are more easily accomplished.

2. Removal of snow is more readily effected and less trouble is experienced with snow drifts.

3. The right of way is more easily kept clean.

4. Satisfactory clearances under street viaducts in track depression are difficult to obtain.

5. Signals can be seen more distinctly, especially low signals.

6. The construction is usually less difficult and cheaper.

Depression of Streets. It is usually impracticable to raise the tracks to such a height that the elevation of streets at the crossings need not be altered. The economical height for elevating track naturally depends much upon circumstances, being controlled by the relative cost of constructing the embankment and the cost of depressing the streets with the attendant damage to adjacent property. The elevation of the tracks through the block need not be as great as the distance between grades at the street crossings, but it is impractical to drop the grade of the tracks through the blocks and raise it again over each street crossing, as is commonly done for elevated electric railways in cities. For this reason, it is necessary to adopt a constant amount of elevation to give to the tracks and to accomplish the remainder of the grade separation by depressing the streets. The division between these two distances that will be the most economical arrangement will be such that the total cost, including the raising of the tracks and the depressing of the streets, may be a minimum. This usually occurs when the tracks are elevated 8 to 12 ft. and the streets depressed sufficiently to furnish the remainder of the headroom necessary.

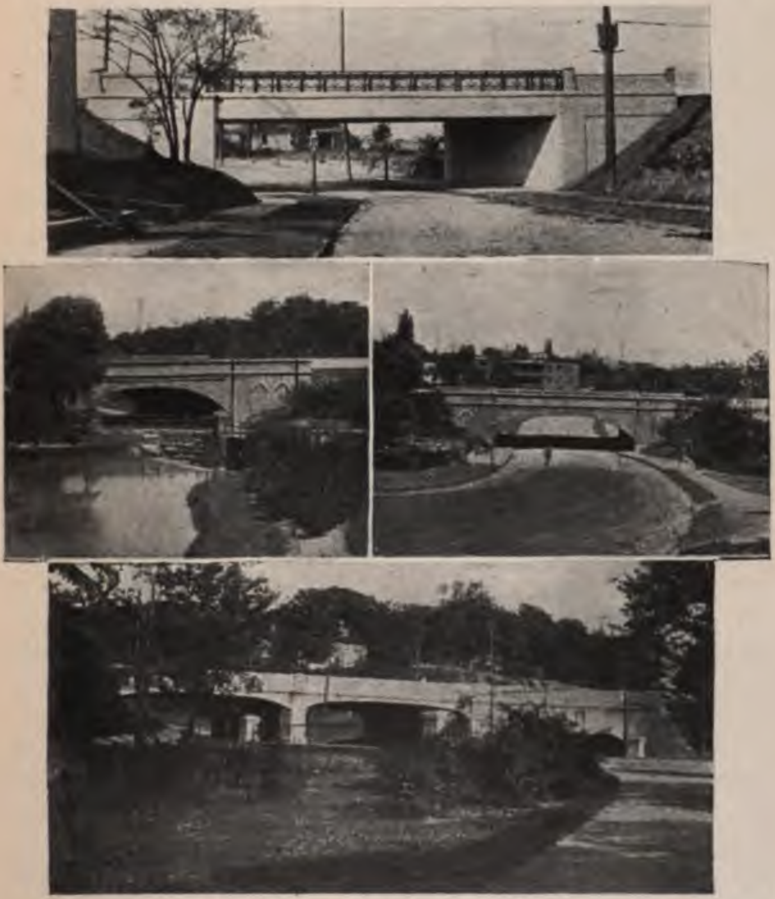

FIG. 55.—Typical Track Elevation Structures.

It is undesirable to use more than a 4 or 5 per cent grade on the street where it is depressed, and consequently it becomes necessary to change the street level for 100 or 200 ft. on either side of the crossing, which entails not only a reconstruction of the pavement, but of sewers and other underground structures as well. Of the latter, sewers cause the most trouble owing to the fact that they have to be kept on a definite gradient. This is sometimes accomplished by deflecting the sewer around the crossing and sometimes by means of an inverted siphcn. The drainage of the depression in the street may constitute a serious problem also.

The character of the street may be modified advantageously where it passes beneath a viaduct or through a subway. The width need not be maintained because there is no occasion for vehicles to stand at the curbs nor for persons on the sidewalks to walk in any other direction than straight ahead, consequently both the street between the curbs and the sidewalks may be made narrower than on the regular street. The level portion under the viaduct should be continued a sufficient distance beyond the structure to permit the highest vehicles to clear before starting up the grade. The height of clear space in the subway should be such as to allow vehicles of maximum height to pass through. This will usually require about

12 to 13 ft. for streets without cars,
12½ to 14 ft. for streets with street cars,
15 to 16 ft. for streets with interurban electric cars.

To secure greater headroom greatly increases the cost of the structure and of the work generally, the cost varying nearly as the square of the depth.

Track Depression. Track depression is accomplished by excavating the right of way and holding back the adjacent earth by means of retaining walls, and then operating the trains over tracks laid in the bottom of the channel thus formed, carrying the streets over the tracks by means of viaducts or bridges. While track elevation is usually the favorite method of separating grades from the point of view of the railway, track depression is frequently preferred by the city for the following reasons:

1. The depression does not obstruct the view as does an embankment.

2. The trains are almost entirely hidden from sight in the depression.

3. The noise is less from depressed tracks at street crossings.

4. The streets are more easily kept clean and sanitary when they are in the open above the railroad than when they pass beneath.

The structures involved in track depression are:

1. Retaining walls to hold back the earth at the sides.
2. An excavated channel in which the tracks are laid.
3. Bridges for carrying the streets and street cars over the tracks.

The bridges used in track depression are naturally lighter than those required in track elevation, but they are necessarily much longer, because the railroad right of way is wider than the streets, and also because the approaches must give sufficient elevation to the streets to enable them to pass over the tracks.

Property Damages. It usually happens in track elevation or track depression work that the damages to property abutting the right of way constitute a considerable portion of the total cost of the work. In the track elevation work on a branch of the Philadelphia and Reading Railway at Philadelphia, the land damages amounted to $82,000, or about one per cent of the total cost, and in many instances, they amount to a much larger percentage than this. It is not uncommon for the city to recognize its responsibility for grade crossing removal and to accept as its share of the expense in that connection the damages accruing to property in the vicinity. Railroads may exercise the right of eminent domain in grade separation procedure, although a settlement outside of court is preferable if it can be secured. Whether the damages are determined by agreement or by arbitration and appraisal, the cost is usually very large.

Damage claims usually arise under common law and equity rights, but in some states the statutes make special provision for such damages. Thus the Missouri statute states: "That private property shall not be taken or *damaged* for public use without just compensation." The courts have established the measure of damages as the depreciation in the value of the property due to the change of grade in front of it, and this depreciation may be determined by the difference in the fair market value of the property or by the sum necessary to adjust the level of the property so that it will have the same elevation relative to the grade line as before the improvement. Ordinarily, the method that shows the least damage is adopted. Indirect damages to industries resulting from the change in grade are not commonly allowed.

Interurban and Street Railway Crossings. Whenever an electric railway, either interurban or urban, is crossed, the possibilities of danger become very grave. Interurban lines should be treated essentially the same as intersecting steam railways. The common practice for street railway crossings is to depend on the street-car conductor to flag his car safely across the track, which, owing to the mediocre discipline and training that ordinarily obtain among street-car employees, does not always prevent accidents. Where the steam trains are operated at full speed, and where the grades on the street railway are such as to prevent the full and complete control of the cars under all conditions, other safeguards should be provided. Owing to the comparative ease of bringing electric cars to a stop and their relatively high accelerating capacity, both of which greatly reduce the loss of time and expense incident to stops, electric lines may cross at grade more satisfactorily than steam roads. The burden of stopping should ordinarily be borne by the electric railway owing to the fact that stops are much more cheaply made due to the lighter cars. The traffic density that will justify the separation of the grades may be determined economically according to the principles previously outlined.

Steam Railway Crossings. Grade crossings on steam railways are usually protected by derails and interlocking devices so that danger of collision at such points is reduced to a minimum. Electric interurban crossings should be thus protected also when they occur at grade. The chief objection to crossings thus protected are (1) the time lost in stopping at the crossing and (2) the cost of making the stops. Where the traffic is very dense, the delays and expense incident to such stops become so great that economy is served by abolishing the grade crossing altogether. At what density of traffic such separation of grades is justified must be determined by a study of each case, for the cost of separation would depend entirely upon local conditions. Where, by virtue of the natural topography, one road can be readily elevated so as to pass over the other, the grades can be very cheaply separated, and very little traffic would be required to justify such separation.

When a complete interlocking plant is established at a crossing, trains rarely have to stop except on roads where the traffic is very dense. However, when traffic becomes very heavy, there comes a time when the capitalized cost of stops, including the time lost, the fixed charges on the interlocker, and the wages of the attendant exceeds the cost of grade separation. When this point is reached, the grades of course should be separated.

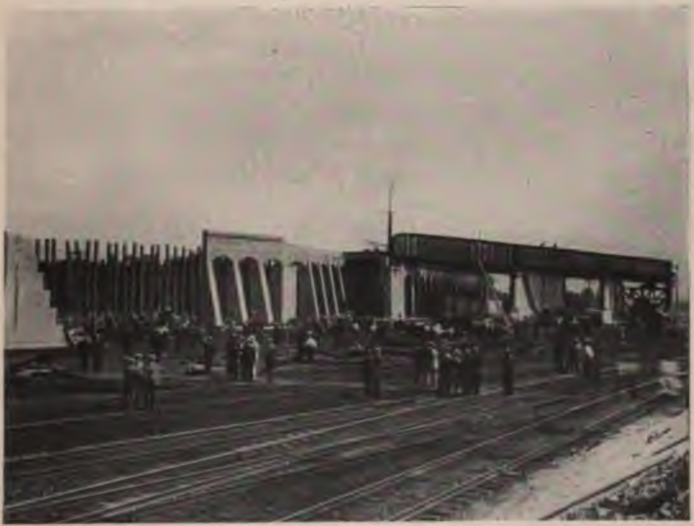

FIG. 56.—Track Elevation on C. & W. I. R. R.

The general effect on traffic of the absence of grade crossings is beneficial, which fact would probably render desirable the separation of the grades even before the effects on the cost of operation would justify such action. In large cities, the separation of grades becomes very complicated and expensive in many instances. Fig. 56 shows the work under construction of separating the grades of the Rock Island and the Chicago and Western Indiana railways, and illustrates the complexity of this work under congested conditions. This work provides for carrying five tracks of the former road over ten tracks of the latter.

The courts have commonly held that priority of construction should be given little weight in distributing the burden of separating grades, and that the roads involved must co-operate to bring about the solution of the crossing problem that is most advantageous to the public service. As a matter of fact, crossings either at grade or separated are usually constructed and maintained according to contracts between the companies involved.

Cost of Grade Separation. Only careful study of the separate items, such as the retaining walls, earthwork, bridges, property damages, track work, cost of conducting transportation during construction, etc., will give a reliable estimate of the cost of track elevation or depression. Each of these items should be analyzed as completely as possible into its elements and units prices assigned to each. However, some general figures as to the cost of grade separation work are instructive by way of comparison with the cost of other work connected with the building or improving of railways.

In the *Railway Age Gazette*, July 19, 1914, Mr. H. C. Estep gives some data on the cost of grade separation work in Massachusetts and Rhode Island, which, he states, represents about average conditions. The structures included in the 20 miles through rural regions and small villages were: 11 overhead timber bridges, 8 timber subways under the railroad, one 70-ft. deck plate girder on masonry abutments, and one 105-ft. span over another railroad, making a total of 22 structures. The total estimated cost of these structures was $103,935, or $5196 per mile of line. The actual cost of the 19 timber structures was $61,577, or $3241 per structure. Approximately two-thirds of this cost was for grading and one-third for the structure itself. Only such grading as was chargeable to grade separation was included. Changes in highway grades and locations were made where deemed advantageous.

On 8 miles in Rhode Island through rural regions, the cost of 4 timber and 2 steel structures was $21,749, or $3625 per structure, the timber structures costing about $1100 and the permanent ones $6000, exclusive of grading.

On 8 miles under city conditions, there were 12 timber and 14 steel and concrete structures, whose estimated cost was $237,426, exclusive of grading, which amounted to $26,400, thus bringing the total to $263,826, or $32,978 per mile.

Summarizing, Mr. Estep says that the timber structures in the country cost about $1200 and in the city about $2300 each. The cost of permanent structures in the country was about $10,000 and in the city about $14,000 each. The whole cost of grade separation costs about $3000 per mile for country conditions and about $30,000 per mile for city conditions.

In Chicago,* 148.7 miles were elevated at a total cost of $72,622,000, or $488,000 per mile.

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* *Engineering News*, June 3, 1909.

CHAPTER XX

ADDITIONAL MAIN TRACKS

Introduction. The railroads of the United States, as has been stated, were chiefly pioneer lines, built when in reality no traffic actually existed, and they were constructed as cheaply as possible due to this fact. Almost without exception they were built as single-track lines, whereas the railways of European countries, notably those of France and Germany, were designed for conditions that already existed for the most part, and as a consequence, they were built with two tracks wherever the second track was warranted. Owing to the fact that the railways of this country have been constructed as single-track lines, as the traffic increases with the denser population it becomes necessary to construct additional tracks. At the present time about 89 per cent of the railroads of the United States are single track. The future railroad building of the country will be more and more concerned with additional main tracks because the country has reached a normal state of population where the growth is at about the same rate relatively in all parts, and the increase in population will probably follow fairly well-established principles that may be observed by studying the census reports.

Additional main tracks will be needed, moreover, owing to the tendency for minor roads to serve as feeders to large and strategically located lines. These latter are destined more and more to become trunk lines that will require two or more tracks to carry the traffic resulting from this arrangement.

While it is impossible to formulate a definite rule by which to determine at what stage in the development of traffic additional tracks become justified, a review of the principles involved will aid in the solution of the problem. Double track is, of course, justified economically when the decrease in operating expenses due to its installation exceeds the fixed charges on the added investment, and this chapter will be occupied in discussing the problem from this point of view.

Alternatives for Increasing Track Capacity. When the traffic of a single-track railroad becomes congested and the line has apparently reached its limit in carrying capacity under existing conditions, additional tracks are by no means the only alternative for increasing the capacity. Various expedients, both in operation and in construction, may be used either to postpone the building of additional tracks or, in some instances, to avoid it altogether.

Grade reduction, as discussed in the preceding chapter, may be used for increasing track capacity instead of double tracking. It is usually advisable to consider the possibilities of grade reduction first, because double-track roads are economical only under heavy traffic, and wherever the grades can be reduced with facility, this method, as has been already shown, offers the most ready means of reducing the cost of operation. Moreover, it is scarcely consistent construction to double track a line on which the grades have not been reduced to the economical minimum. Grade reduction increases the traffic capacity because it enables the traffic to be transported with fewer trains, and it is chiefly the number of trains rather than the tonnage that congests a division owing to the necessary delays at meeting places.

The introduction of block signaling will also increase the capacity of a line by allowing trains to run closer together than can be safely done without them. Sometimes a rearrangement of the blocks, shortening the length of the blocks, or using the permissive absolute system instead of the absolute, where the traffic is almost entirely freight, may serve to give a congested division greater capacity.

A rearrangement and enlargement of terminals may be possible, which, by allowing trains to get out on the tracks at the proper times to avoid unnecessary interference, may afford the needed increase in capacity. Most of the delays that occur to freight movement take place in terminals, consequently terminal improvement may be a fruitful field of study in attempting to bring about greater carrying capacity.

The fleet system of train despatching has been used on crowded freight lines. In this system the trains are all moved in one direction for a certain period and then those bound in the other direction are moved forward while the former wait on sidings or at the terminals. This means is applicable only where the traffic is practically all freight of one class such as on ore or coal roads.

Care in despatching in order to avoid bunching trains at certain times of the day may bring a modicum of relief on congested divisions. Dispatching freight trains at times when the track is least occupied by passenger trains will also be an advantage.

Increasing side-track facilities will increase the capacity of a single-track line. As shown in a previous chapter (Chapter XII), there would be no delay due to waiting for trains if the trains were dispatched one after another at intervals equal to twice the running time between passing points, but such a mathematical operation of trains is, of course, impracticable. The interval between sidings varies from 4 or 5 miles on busy roads in thickly populated districts to almost any distance in sparsely settled communities with very light traffic, and the length of sidings varies from that which is just sufficient to accommodate the longest train to a length that is in reality a short stretch of second track. Side-track facilities may be increased by (1) shortening the interval between sidings, (2) increasing the length of certain side tracks to form *relief tracks*, and (3) rearranging the side tracks so that they will afford an opportunity for superior trains to pass freight going in the same direction with them as well as freight bound in the opposite direction. This may be accomplished by the use of lap sidings with cross-overs with interlockers. The limits of increasing side tracks will be pointed out in a succeeding paragraph.

The *use of heavier motive power* enabling longer trains to be hauled, thereby reducing the number of passings and meetings necessary, will also increase the capacity of single track.

Duplicate tracks up long steep grades, where speed is necessarily slow for heavy freight trains, which permit faster trains to pass the heavy freights in the upbound direction, is a device for increasing the operating capacity that is frequently utilized.

Placing double track at stations so that trains may pass and meet each other without involving stops other than the usual station stop will diminish the delays due to trains taking the sidings.

Electrification is a method of increasing capacity that promises to be used much in the future.

Railroads almost invariably employ some of these means of increasing the carrying capacity of the track before double tracking is resorted to. The correct solution of the problem largely depends upon the character of the traffic as well as the amount.

Influence of the Character of the Traffic. Not only the density of traffic, but the character of the traffic as well, affects the degree of congestion of movement on a railroad. Where the traffic is all of one kind, the maximum density of traffic can be handled, and conversely, the greater the diversity of traffic the less the amount that can be handled. If all of the traffic is low grade freight, e.g., ore, coal, etc., trains can be run closely together and none need be greatly delayed because of waiting to allow a superior train to pass. A similar condition exists on electric lines, such as street railways and interurban railways, where the traffic is of one kind. When, however, the traffic consists of through slow, fast and local freight, as well as local and express passenger trains, the freight movements are greatly delayed. From the viewpoint of freight movement, passenger trains are but obstructions to the running of trains, a fact that should be kept in mind in many other connections as well as in the present discussion. Where frequent suburban traffic is to be accommodated, two or more tracks are almost absolutely essential. Trains hauling live stock and perishable freight always delay the slower freight trains in a manner similar to the effect of passenger trains. With many fast freight and passenger trains, the slow freights may be kept on sidings practically all day and be allowed on the main line only at night. The loss in use of equipment, revenue and wages may amount to a large sum under such circumstances.

Physical Limit of Capacity of Single track Railroads. The capacity of a single-track railroad depends upon several conditions, among which may be mentioned the character of the traffic, the speed of the trains, and the spacing of the sidings. The capacity varies directly with the speed of the trains and inversely with the distance between the sidings. That this is true can be shown by an illustration more simply than by an extended proof. Assume that trains are moving at the rate of 28 M.P.H. and the passing sidings are 7 miles apart, then the capacity will be $28 \div 7 = 4$ trains or 2 each way per hour; if the velocity be only 14 M.P.H., the capacity will be $14 \div 7 = 2$

trains or one each way per hour, for only one train can pass over the line between two sidings in the interval required for a train to run this distance. Again, the speed of any train over a given division is dependent on the tonnage of the train, hence the equation may be written

$$t=24\frac{VW}{D},$$

where t is the capacity in tons both ways per day, V the average speed between sidings, including the stops on the sidings, D the distance between the sidings, W the tonnage rating of the locomotive for the district.

This equation represents the capacity between two sidings under ideal conditions with no passenger trains, and all freight trains having the same average speed. The two sidings on the district whose spacing is such as to give the minimum capacity will limit the capacity of the division, for traffic cannot move over the division more rapidly than through the most restricted section. This equation is predicated on the assumption that the trains are dispatched at equal intervals throughout the day and that there are no breaks in the operation, a condition that never obtains in practical operation. However, the equation shows the essential relationship between the passing siding interval and the capacity, which will be further illustrated by an example.

Consider a district 100 miles long with 20 passing sidings spaced as shown in the table below. Applying the formula gives the capacities shown, with the minimum capacity at the 14th siding interval of 96,000 tons per twenty-four hours as limiting the capacity of the entire division. If the distance between these two sidings is changed to 6 miles, the capacity is increased to 125,000 tons. The same result might be accomplished by reducing the gradient so that 21 M.P.H. could be maintained as the average velocity at this point.

If twenty-two minutes be assumed as lost by waiting on the sidings, observing the clearance rule of ten minutes on a line without block signals, etc., the speed is reduced over this restricting territory to 9.2 M.P.H., and the capacity consequently reduced to 55,200 tons per twenty-four hours. If block signals be installed, obviating the ten-minute clearance, the average speed becomes 11.4 M.P.H., and the capacity increased to 68,400 tons per twenty-four hours. From this, the interdependence of speed, spacing of sidings, and signal facilities becomes apparent. Grades, excessive curvature, or other features that limit speed at this point, become sources of serious loss, since the capacity is greatest where conditions are favorable for maximum speed.

OPERATING CAPACITY OF SINGLE TRACK

Distance between passing tracks, miles	2	5	3	5	6	6	5	3	4	5
Average speed, M.P.H.	8	20	12	20	20	20	20	12	20	16
Capacity in thousand tons per twenty-four hours	192	192	192	192	160	160	192	192	240	153

Distance between passing tracks, miles	7	2	5	8	3	7	4	6	5	9
Average speed, M.P.H	25	24	20	16	12	25	16	24	18	20
Capacity in thousand tons per twenty-four hours	171	576	192	96	192	171	192	192	192	106

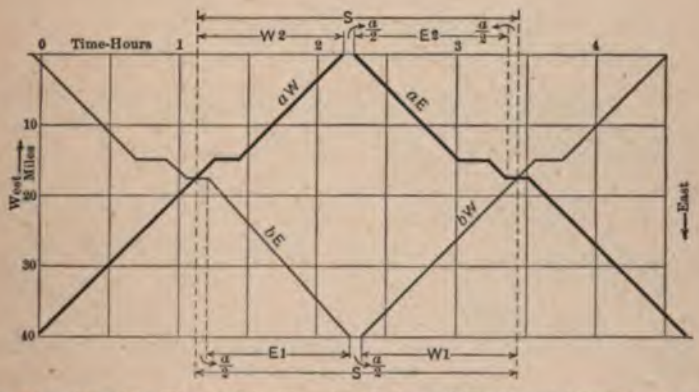

FIG. 57.—Graphic Time-table Showing Delay of Trains at Meeting Points.

A more definite relation between operating conditions and the capacity of a single-track railroad may be derived as follows:*

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* Proc. Am. Ry. Eng. Assn., Vol. XVII, p. 72.

Let S = the spacing between trains in the same direction;
T = number of trains per day;
a = delay of a train at a passing siding.

Then

$$T=\frac{1440\times 2}{S} \text{ (1440 minutes in a day).}$$

The value of S may be determined as follows: Assuming that W_2, Fig. 57, represents the time of the westbound train running between the passing siding and o, and W_1 the time running between the passing siding and 40, and E_2 the time consumed by the eastbound train in running between o and the passing siding, and E_1 the time between the passing siding and 40, and also letting a represent the time consumed by a train taking the passing siding to meet another train, we have from the diagram:

$$S=W_1+E_1+\frac{a}{2}+\frac{a}{2};$$

also

$$S=W_2+E_2+\frac{a}{2}+\frac{a}{2};$$

or

$$2S=W_1+W_2+E_1+E_2+a+a$$

or

$$S=\frac{W+E+2a}{2}.$$

If N equals the number of passing sidings, then, substituting in the last equation $N+1$ for 2, we have:

$$S=\frac{W+E+(N+1)a}{N+1}.$$

Substituting this value of S in

$$T=\frac{2880}{S},$$

we have

$$T=\frac{2880(N+1)}{W+E+(N+1)a},$$

which gives the maximum number of trains that can be operated over a single-track railway.

Limit of Side-track Facilities. Obviously a double-track line has a greater capacity than two single-track lines, because delays at meeting points are avoided and delays due to superior trains passing inferior trains are about the same in the two cases. The economic spacing of passing sidings is found for average conditions to be about 4 to 4.5 miles apart to give the maximum capacity under most conditions, for if greater than this, the capacity is limited, as shown in a previous paragraph, and if they are closer, the time lost in turning out will be greater than the running time. When the practical limit of the capacity of a single-track line with sidings has been nearly reached, relief tracks are usually built as extended side tracks at the end of the district and operated as second track; relief tracks are also built frequently at intermediate points, so that instead of waiting for the opposing train to pass, the train on the siding can keep on moving for some distance at least. The relief tracks are first built at the ends of the division, because of the greater number of obstructions encountered there. Gradually these sidings grow until it is found desirable to double track the entire district.

Economic Limit of Single-track Railroads. While the above discussion indicates the physical limit of the capacity of a single-track railroad, the economic limit is usually reached before the physical limit is attained, and the next few paragraphs will be occupied with an attempt to determine the economical limit of single-track lines. The economic limit of capacity depends chiefly upon the relative cost of operation under the single-track conditions and the fixed charges on capital required to construct the second track; that is, the arrangement is most economical that will cause the fixed charges invested in sidings, plus the cost of operation, to be a minimum. The loss of time due to delays at the sidings, the loss of capacity and efficient use of the existing facilities, the losses in fuel and wages due to stops and delays, the greater danger of collisions, etc., must be balanced against the cost of constructing the additional track.

Loss of Time for Equipment and Crews. In the Proceedings of the Master Mechanics' Association of June, 1905, it is stated that locomotives are on the road about 75 per cent of the time, much of which is taken up by delays. In one case mentioned, which is typical, one locomotive was on the road 464 hours in one month with 266 hours delay, 128 of which were occasioned by the passing of trains. The average speed of this locomotive during the time it was in the hands of the transportation department was 5.7 M.P.H. Records kept on the Southern Pacific Railroad * showed that the time consumed in stops on " freight runs having physical characteristics similar to the Wabash east of Toledo, varied from thirty seconds to one minute per mile run on single-track line, according to the density of the traffic." On the Wheeling and Lake Erie, a line with very dense traffic, the time lost on through-freight runs averaged a little more than three minutes per mile run. While the latter figure is abnormally high, due to the congestion of traffic, yet under ordinary conditions, the time lost in delays due to passing trains on single-track lines amounts to 15 or 20 per cent of the total running time. The expense due to delay of equipment, counting freight cars at 45 cents per day each, and a locomotive at $10 per day, together with the cost due to extra wages of train crews in case of overtime, can be readily estimated.

Cost of Stopping and Starting a Train. The factors that are involved in the cost of stopping and starting a train are variable, and the exact figure cannot be computed, but a statement of the factors entering into the question will enable an estimate to be made for any given conditions. The chief ones are:

a. Cost of fuel.
b. Cost of water.
c. Wages of crew.
d. Wear on brake shoes.
e. Wear on tires.
f. Wear on brake rigging.
g. Wear on draft gear.
h. Consequential delays to other trains.
i. Loss of revenue.
j. Additional fixed charges.

The cost of fuel includes three items, (1) fuel for applying and releasing air brakes, (2) fuel burned while coasting and standing, (3) fuel burned in accelerating the train. From this total fuel should be deducted the amount that would be consumed

* *Eng. News*, Apr. 4, 1907.

in normal running in order to ascertain the fuel cost chargeable to the stop.

The ordinary locomotive air compressor uses about 3 to 4 lbs. of coal per hour while working, or about .001 lb. per second. A locomotive burns about 1 lb. of coal per second while pulling at the maximum rating, and perhaps one-fourth or one-fifth that amount while standing or coasting. An estimate of the amount of fuel burned while standing and coasting may be made from Table XXXIII. The work done in accelerating a train to V miles per hour is $\frac{1.13WV^2}{g}$ or $\frac{1.13WV^2}{1{,}980{,}000g}$ horsepower hours. About 5 lbs. of coal are required per horsepower hour, hence the coal required for acceleration will be $.00017TV^2$ lb., T being the weight of the train in tons. One pound of coal is sufficient to evaporate about 7 lbs. of water ordinarily, hence the water used may be taken as .84 times the weight of coal.

The amount of wear on the brake shoes and wheels is small for any one stop. A brake shoe weighs about 20 lbs. and will last about 5000 car-miles, or perhaps 1000 miles with the brakes applied. Purdue University tests showed that brake shoes lost about 1.5 lbs. per 100,000 ft.-tons of energy dissipated by the brakes. Hence, a reasonable estimate would be, if the stop is assumed to be made in one-fourth mile, that $\frac{1}{4000}$ of each shoe is worn off at each stop. With 8 shoes to the car and cast shoes at 4 cents per pound, this would be 0.064 cent per car per stop, and probably the wheels are damaged an equal amount and at a somewhat higher price for the casting.

In the absence of more reliable data, the brake rigging may be assumed to be damaged an amount equal to the brake shoes.

The draft gear may give way at one stop and it may withstand all stops as long as the car lasts. However, on the basis of the average life of draft gear and a reasonable assumption as to the number of stops, probably 0.2 cent per car would be a fair estimate of the damage done to draft gear at a stop.

No general estimate of the loss due to delays of other trains occasioned by the stop can be formed, because such losses would depend entirely on the traffic conditions. The minimum stop that would allow the release of the brakes would probably be about one minute, making a loss of 1½ minutes.

Summarizing these losses for a 2500-ton train, with 80 cars, stopping in ¼ mile, two minute stop, and requiring thirty seconds to attain a speed of 25 M.P.H., the fuel consumed would be about as follows:

	Lb.
Brakes .001×80×30=	2.4
Coasting and standing	22.5
Accelerating .00017×2500×625	262.0
	286.9
Less 30 lbs. for normal running	30.0
	256.9

The cost would then be,

Fuel at \$3.00 per ton	\$.400
Water at 15c. per 1000 gals	.015
Crew wages at \$2.50 per day	.055
Brake shoes and tires	.100
Brake rigging	.050
Draft gear	.160
Total	\$.780
Fixed charges	.020
Total cost of stop	\$.800

With transportation worth about .75 per ton-mile and with say 800 revenue tons in the train, about ⅓ mile could have been covered in the time lost, hence the lost transportation would be ⅓×800×.75=\$2.00, less perhaps \$0.25 for operating expenses, or perhaps \$1.75, which would represent a possible additional loss in the event that the equipment of the railroad were working to its utmost capacity. Where the nature of the freight hauled is of a class that produces a higher tariff rate, this loss due to decreased capacity may be considerably increased. Moreover, in handling live stock, a certain amount of damage may result to the live stock from the shocks involved in stopping and starting. Thus the indirect costs of a stop may be much greater than the direct effect on the cost of operating the train, and under extreme conditions may make the total cost, including direct and indirect effects, to amount to four or five dollars per stop per train.

Diminished Danger Due to Additional Tracks. Collisions are about the only type of accident that may be prevented by the construction of additional tracks, and only head-end collisions would be obviated, which, as a matter of fact, constitute a very small percentage of the total accidents of a railroad. In 1912, the proportion of passengers killed in collisions was 18 per cent of the total killed, and in 1913 it was 35 per cent of the total. While double tracking may diminish the total number of head-end meetings, it would have no effect on the rear-end collisions, from which the most serious accidents occur. These result chiefly from a failure on the part of the engine driver for one reason or another to obey the signals. Many of the most disastrous accidents of this nature in recent years have occurred on double-track lines that were fully equipped with approved block signals. It is doubtful if the decrease in danger of head-end collisions would more than counterbalance the increased danger at crossings and at other places that are inherent in double-track operation. However, there is a general feeling of greater security while traveling on double-track roads, hence, the moral effect on the traffic would be beneficial. With the same average speed of trains, it is probable that the danger of collision on double-track roads is somewhat less than on single-track lines.

Cost of Second Track. The relative cost of first and second tracks varies with the conditions, chiefly with the character of the topography over which the original roadbed was built. The cost of track items, viz., rails, ties, fastenings and ballast, is obviously as much for the second track as for the first, except that the improved facilities for handling these articles resulting from the use of the first track will materially reduce the cost of construction. The cost of earthwork will always be much less for the second than for the first track, since the yardage for the side slopes will not be increased and the only material that will be added will be that involved in providing for the extra width of roadway necessary for the second track, or in other words, the depth of fill multiplied by the distance between track centers. See Fig. 58. Not only is there much less material to handle, but the existing track enables the earthwork to be handled much more cheaply than can be done in the original construction. Under ordinary conditions (fills and cuts not over 18 ft. in depth), the amount of earthwork is not more than 40 per cent of that involved in the original construction, and the improved facilities would probably enable it to be handled at 85 or 90 per cent of the original cost per cubic yard, hence, the earthwork cost under such conditions may be about 35 per cent of that of the original construction. With deeper cuts and fills the percentage grows less.

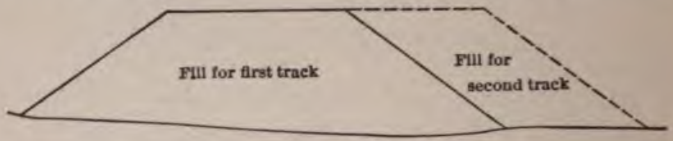

Fig. 58.—Additional Fill for Second Track.

Bridges and culverts may have 50 to 60 per cent added to their cost in providing the necessary width and strength for the second track.

Without discussing each item in detail, an estimate of the proportional cost of second track is indicated in Table LII.

Table LII

COST OF SECOND TRACK

Item.	Per Cent of Whole.	Proportion Affected for Double Track.	Per Cent of Original Cost.
Right of way	5.0	20	1.0
Terminals	11.0	00	0
Bridges and culverts	9.0	50	4.5
Grading	26.0	35	19.0 9.1
Track materials	14.0	100	14.0
Track laying	1.5	80	1.2
Ballast	6.5	100	6.5
Fencing	1.0	0	0
Telegraph	0.5	0	0
Stations	1.0	0	0
Fuel and water stations	1.5	0	0
Engineering	1.5	10	0.2
General and legal	1.5	10	0.2
Equipment	20.0	0	0
Total	100.0		36.4 26

The first column gives a fair average of the division of costs among the various items of construction, and the cost of second track is estimated therefrom. This mode of procedure indicates that the total cost of second track is approximately 36 per cent of the cost of the first track.

The above relation between the cost of the first and of the second track, however, may be far from correct on mountain divisions, where the additional width of roadway required may be obtainable only at great expense. Double tracking mountain districts is usually so expensive that in most instances it will be found advisable to investigate the alternatives for increasing the capacity of single track, mentioned at the beginning of this chapter, before undertaking the construction of the additional track.

Cost of Maintenance. Naturally, as in the original construction, the cost of materials involved in the maintenance of double track will be approximately twice that for single track for the same conditions of traffic. However, with any given traffic, the cost of materials required to maintain double track will not be twice that for single track, since the wear on rails and to some extent on ballast, ties and other track material is dependent upon the amount of traffic. For a given tonnage, the rail renewals will be nearly the same for double track as for single track per mile of line, perhaps 5 to 10 per cent more due to rusting. Trackwork is increased somewhat, but not doubled. Sections are commonly 6 or 7 miles long on single track and 4 or 5 miles long on double track. However, this ratio represents better maintenance as the usual practice on double-track lines rather than the actual relative difficulty of maintenance. The cost of maintaining line and surface is probably between 50 and 75 per cent more for double track than for single, but fence repairs, mowing weeds, cutting brush, keeping up snow fences, protecting banks, and other work of this class are not materially increased, the entire additional cost for this item being perhaps 10 per cent. Table LIII summarizes the effect of second track on maintenance costs, from which it is seen that the cost of maintaining double track is about 45 per cent greater than for single track.

TABLE LIII

COST OF MAINTENANCE OF DOUBLE TRACK

Item.	Per Cent of Maintenance Expenses, 1914.	Proportion Affected, Per Cent.	Increased Cost, Per Cent.
Ballast	1.77	50	0.89
Ties	16.45	90	14.81
Rails	4.66	20	0.93
Other track materials	5.25	10	0.53
Roadway and track	36.70	60	22.02
Removal snow, etc	1.45	80	1.16
Tunnels	0.27	10	0.03
Bridges, etc	8.95	50	4.47
Roadway, tools, etc	1.33	50	0.66
			45.50

Effect of Additional Tracks on Revenues. Owing to a very small margin between total receipts and total expenditures in railway operation, any agency for increasing gross revenue should not be overlooked. Furthermore, it has been repeatedly demonstrated to be good policy to provide additional facilities in advance of the actual requirements. In arranging through schedules, minor feeding lines give preference in general to those roads that can take care of the business to the best advantage, and hence, double-track lines would be given preference in routing traffic, and thereby increase revenues somewhat. It is impossible to state how much double tracking may increase revenues, but the improved facilities without doubt attract freight business and the added sense of security and the greater speed possible appeal favorably to travelers. A study of the growth of traffic on all roads shows an increase in business after double track was installed, but it is impossible to determine how much of the increase was due to the installation of second track, and indeed, the second track may have been the result of prospective business rather than the cause of its growth.

Effect of Second Track on Operating Expenses. Double tracking increases maintenance of way expenses, but decreases transportation costs. Table LIV gives an estimate of the effect of second track upon operating expenses when the time lost by freight trains is about 15 to 40 per cent.

TABLE LIV

EFFECT OF SECOND TRACK ON OPERATING EXPENSES

For various percentages of time lost on sidings.

Item.	Average Per Cent.	Proportion Affected for Per Cent of Time Lost.			Per Cent of Operating Expense for Per Cent of Time Lost.		
		15%	30%	40%	15%	30%	40%
Ballast..................	0.33	50	50	50	0.17	0.17	0.17
Ties.....................	3.07	50	50	50	1.53	1.53	1.53
Rails....................	0.88	10	10	10	0.09	0.09	0.09
Other track material......	0.99	10	10	10	0.10	0.10	0.10
Roadway and track.......	6.85	30	30	30	2.06	2.06	2.06
Removal of snow, etc.....	0.27	50	50	50	0.13	0.13	0.13
Tunnels..................	0.05	20	20	20	0.01	0.01	0.01
Bridges, etc..............	1.69	20	20	20	0.34	0.34	0.34
Crossings................	0.40	50	50	50	0.20	0.20	0.20
Total increase........	....	.....	.....	.....	4.64	4.64	4.64
Signals and interlocking...	0.55	−10	−10	−10	0.05	0.05	0.05
Sidings..................	0.33	0	−15	−20	0	0.05	0.07
Steam locomotive.........	9.34	−10	−20	−30	0.93	1.87	2.81
Passenger cars...........	1.85	−10	−20	−30	0.19	0.37	0.56
Freight cars.............	11.11	−10	−20	−30	1.11	2.22	3.33
Dispatching trains........	0.85	−20	−30	−40	0.17	0.25	0.34
Road enginemen..........	5.95	−10	−20	−30	0.59	1.19	1.79
Enginehouse exp. rd.......	1.69	−10	−20	−30	0.17	0.34	0.51
Fuel road locomotive.....	8.65	− 3	− 5	− 8	0.26	0.43	0.69
Other sup. locomotive....	0.96	− 3	− 5	−10	0.03	0.05	0.10
Road trainmen...........	6.40	−10	−20	−30	0.64	1.28	1.92
Train supplies............	1.74	−10	−20	−30	0.17	0.35	0.55
Total decrease.......					4.31	8.45	12.72
Net saving..........	....	.....	.....	.....	−0.33	3.81	8.08

Second track is justified when the saving in fixed charges on rolling stock and on sidings plus the saving in operating expense which would result from the installation of second track is equal to the interest on the money required to construct the second track. For example, assume on a 100-mile division, the cost of second track to be $12,000 per mile and of sidings $8000 per mile. Assume the sidings at 15 per cent of the total mileage under moderate traffic and 25 per cent under conditions demanding second track, then 10 per cent, or 10 miles, would represent the saving in length of sidings due to second track, the lesser amount of sidings being retained on the double track. Suppose that the three percentages of time lost represent, for 15 per cent, 2 passenger and 5 freight; for 30 per cent, 5 passenger and 10 freight, and for 40 per cent, 7 passenger and 18 freight trains each way per day, then the annual saving in operating expense with double track, according to Table LIV, is as follows:

For 15 per cent lost time, $\$1.76 \times 365 \times 2 \times 7 \times (-0.33) = -\$2965$ (loss);
For 30 per cent lost time, $\$1.76 \times 365 \times 2 \times 15 \times 3.84 = \$7400$
For 40 per cent lost time, $\$1.76 \times 3 \times 365 \times 2 \times 50 \times 8.08 = \$52{,}000$

The total saving might be calculated as follows:

	15 Per Cent.	30 Per Cent.	40 Per Cent.
Passenger train investment	$200,000	$500,000	$700,000
Freight train investment	400,000	800,000	1,440,000
Total rolling stock	600,000	1,300,000	2,140,000
Assumed per cent saving	10	20	30
Decreased investment	60,000	260,000	642,000
Do. in sidings	....	40,000	80,000
Total	60,000	300,000	722,000
At 6 per cent interest	6	6	6
Saving in fixed charges	3,600	18,000	43,320
Saving in operating expense	−2,965	7,400	52,000
Total saving	$635	$25,400	$95,320

The last amount capitalized at 6 per cent would be $1,590,000, which would probably be sufficient to construct the second track.

From the above, it is seen that under normal conditions of traffic, that is, with a time loss of 15 to 20 per cent, the maintenance of way expenses may be increased perhaps 25 per cent, but economies in conducting transportation make the total increase in operating expenses not more than possibly 2 to 5 per cent. If the loss in time for freight trains at passing sidings is greater than this, the transportation expenses increase rapidly, and when the time lost amounts to about 40 per cent of the time on the road, the saving in operating expenses is about sufficient to pay the fixed charges on the cost of constructing the second track.

Over a 100-mile division, for example, with passing sidings 5 miles apart and the speed of freight trains 20 M.P.H. between stations, the time lost for half of the trains would be about 15 minutes for each train passed. Assume eight hours as the time required to run over the division, 40 per cent of which would be 192 minutes. If the traffic density for this eight hours is twice the average for the day, then $\frac{15N}{2}=192$, or $N=26$, approximately, trains each way per day, making a total of 52 trains before the second track is justified.

When the Erie R. R. installed second track between Meadville and Corry, it eliminated about 1100 engine-hours, or forty-eight engine-days per month. Under single-track conditions, the average delay between terminals was two hours and thirty-four minutes for manifest freight, and three hours and fifty-three minutes for ordinary freight eastbound, and two hours and four hours and thirty-five minutes for manifest and ordinary freight respectively westbound.

Practical Limit of Single Track. In the *Railway and Engineering Review*, March 15, 1902, occurs a symposium on the limit of single track from which the following is extracted:

"It might be considered necessary to double track a road when the time of getting trains over the line is twice as long—caused by meeting trains and allowing superior ones to pass—as it would be were there no trains to contend with whatever.

"A railroad should not be double tracked until its grades and curves have been reduced to the lowest practical limit; the roadbed thoroughly ballasted and equipped with 80 to 100-lb. rails; the limit in weight and capacity of power for economical freight-train operation supplied; and passing sidings of sufficient length to accommodate two of the longest trains, which sidings should be spaced 6 or 7 miles apart and arranged so that they will form part of the second track. Then when the traffic justifies the running of over 18 trains in each direction daily, or one train every ninety minutes, the second track should be put in, especially if the traffic is regular throughout the year, or for a period over four months.

"Fifty trains could be handled each way on a division successfully, not to exceed 100 to 110 miles, where everything is favorable, such as weather, grades not too heavy and long, engines properly rated and in good condition, track in good shape, water tanks at least every 20 miles, good long side-tracks not over 6 miles apart, capable of holding any two of these trains.

"In a general way, a road having 60 trains in twenty-four hours, even with ample side-track facilities, and an average proportion of passenger trains, should be considered as requiring double track. Of course, if there were many fast through-passenger trains and fast through-freight trains, it would likely be found to be advisable to provide double track when the number of trains reaches fifty."

An instance was cited where 70 trains per day were handled, 10 of which were passenger trains, over a single-track road.

In *Engineering News*, Sept. 14, 1905, the following statements were given out as the practice on two railroads, indicating the number of trains daily that would justify double track:

On the Pennsylvania Railroad, 60 trains with 20 per cent passenger trains were deemed sufficient to justify double track.

On the Union Pacific Railroad, 50 trains were considered the limit of single track.

In addition to the above considerations, it should be noted that owing to the fact that during the period of construction of the second track, many extra work-trains will have to be handled, it is advisable to begin double-track work some time before the limit of the single track is reached. Fig. 59 shows traffic density in train-miles per mile of line annually plotted against percentages of additional track for a number of roads in the United States.

More than Two Tracks. Increased weight of traffic may give rise to conditions that would justify three, four, or six tracks. A third track is built chiefly as a relief track over heavy grades for the slower freight trains in order that the faster trains in the upbound direction may pass the slow trains without the loss of time on the part of either. The density and conditions of traffic that will justify the third track can be arrived at in a manner similar to that outlined in the preceding paragraphs. The third track will cost about the same proportion of a single track or a little less than the second track does, and the proportionate maintenance expenses will be approximately similar. The savings effected by means of the third track consist of those economies depending upon the decrease in lost time on the part of both passenger and freight trains, such as less fuel, diminished train crew wages, greater usefulness of equipment, etc.

Four tracks, one for passenger and one for freight traffic in each direction, are provided on those railroads carrying a very dense and diversified traffic. Suburban lines out of large cities ordinarily have tracks for suburban trains separate from those used by the through trains. In some instances, through and local tracks are provided in each direction, making a total of six tracks. Where limited through trains are operated between termini, four tracks are especially advantageous in allowing such trains to maintain the maximum speed. Four tracks constitute one step further in separating the traffic in each direction and providing a separate track for each class of trains. The conditions under which four or more tracks are justified have not become general in America, and perhaps will not for many years, unless steps be taken to arrange main trunk lines with outlying railroads as feeders.

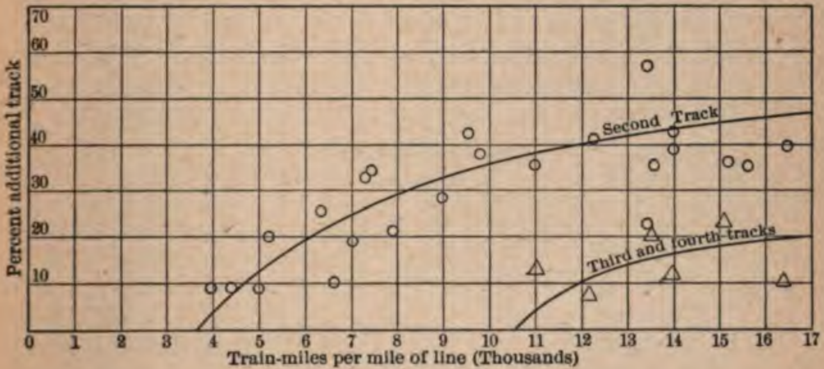

FIG. 59.—Traffic Density and Additional Main Tracks.

Traffic Density on American Railroads. Many questions of railroad location depend upon the density of the traffic to be carried. The average traffic density for the United States in 1913 was 1,220,000 tons per mile of line. The average number of trains over all the roads was 5000 for the same year, or nearly 14 per day over each mile of road. Below are given the density of traffic on a number of busy single-track railroads of the United States.

Railroad.	Train-miles per Mile of Line.
Cleveland, Akron & Cincinnati	3200
Grand Rapids & Indiana	3380
Vandalia	6820
Lake Erie & Western	3670
Toledo and Ohio Central	6280
Wabash	6480
Chicago, Indianapolis & Louisville	5620
Toledo, St. Louis & Western	4980
Atlantic Coast Line	3810
Louisville & Nashville	6120
Nashville, Chattanooga & St. Louis	5730
Central of Georgia	3610
Southern	4880
Southern Pacific (9% double track)	3500
Chicago, Burlington & Quincy (9% double track)	3990
Colorado & Southern	3100
Minneapolis, St. Paul & Sault Ste. Marie	3020
Atchison, Topeka & Santa Fe (9% double trk.)	4500
Oregon Short Line	3630
Chicago & Northwestern (9% double track)	5030
Chicago, Minneapolis & Omaha	4830
Chicago, Rock Island & Pacific	4520
Chicago, Mil. & St. Paul (9% double track)	4430
Great Northern	3110
St. Louis & San Francisco	2780

Table LV gives the traffic density on a number of roads having two or more tracks.

Table LV

TRAFFIC DENSITY ON MULTIPLE-TRACK RAILWAYS

Railway.	Per Cent Double Track.	Per Cent of Third and Fourth Tracks.	Train-miles per Mile of Line.
Long Island	35	....	15,600
Michigan Central	33	....	7,300
Phila., Balt. & Wash.	35	....	13,200
Balt. & Ohio	28	....	9,000
Central of N. J.	39	....	14,000
Del., Lack. & West	56	....	13,300
Lehigh Valley	42	....	9,560
Del. & Hudson	38	....	9,820
Buff., Roch. & Pittsburg	34	....	7,300
Ill. Central	10	....	6,730
Norfolk & Western	21	....	7,990
Chesapeake & Ohio	25	....	6,280
Union Pacific	20	....	5,180
Chicago & Alton	19	....	7,060
Pennsylvania	36	23	15,200
New York Cent. & H. R.	42	11	14,000
Lake Shore & Mich. S.	35	13	11,000
Pittsburg & Lake Erie	73	23	13,500
New York, N. Hav. & H.	41	7	12,200
Phila. & Reading	39	10	16,500

Additional Main Tracks in the United States. Most of the trunk lines of the eastern portion of the United States have two or more tracks and the trunk lines between Chicago and New York, between St. Louis and Chicago, and between St. Louis and eastern points have double track. Generally speaking, the roads extending west of Chicago are just now attaining that density of traffic that justifies double track. Table LVI indicates the mileage of additional main tracks in the various Interstate Commerce Commission groups in the United States.

TABLE LVI

MILEAGE OF ADDITIONAL TRACKS IN THE UNITED STATES

Group Covered.		Single Track, Miles.	Second Track, Miles.	Third Track, Miles.	Fourth Track, Miles.	Yard Tracks and Sidings, Miles.	Total All Tracks, Miles.
I. Me., N. H., Vt., Mass., R. I., and Conn......	1913	7,849	1,602	142	132	3,918	13,643
	1890	7,425	1,248	29	19	2,399	11,120
II. N. Y., N. J., Penn., Del., Md., and Dist. of Col.	1913	22,399	7,916	1336	1015	17,045	49,711
	1890	17,237	4,948	664	507	7,533	30,899
III. Ohi, Ind., and So. Pen. of Mich.............	1913	26,087	5,629	829	491	15,136	48,172
	1890	20,903	1,048	12	3	6,179	28,145
IV. Va., W. Va., N. C. and S. C.................	1913	14,953	1,514	16	4	5,412	21,899
	1890	8,658	26	.....	.....	1,115	9,799
V. Ga., Fla., Ky., Tenn., Ala., and Miss........	1913	25,794	616	.....	.....	7,456	33,866
	1890	15,877	4	.....	.....	2,149	18,300
VI. Ill., Ia., Wis., Minn. and parts Mich., Mo., N. D. and S. D............	1913	49,819	4,295	216	140	17,584	72,054
	1890	38,198	1,012	54	31	7,594	46,889
VII. Neb., Mont., Wyo. and parts of Colo., N. D. and S. D............	1913	18,403	1,429	29	15	15,947	25,823
	1890	8,807	13	.....	.....	1,307	10,127
VIII. Kan., Ark., Okla. and parts of Mo., Colo., Tex., and N. M......	1913	36,013	2,394	21	8	11,085	49,521
	1890	21,173	93	2	1	3,111	24,380
IX. La., Tex. (except Panhandle) and parts of N. M..............	1913	16,811	126	8	.....	4,371	21,316
	1890	7,988	.....	.....	.....	936	8,924
X. Wash., Ore., Cal., Ida., Nev., Utah, Ariz., and parts N. M...........	1913	24,049	799	9	9	6,787	31,653
	1890	10,135	45	.....	.....	1,387	11,567
United States................	1890	156,404	8,437	760	561	33,711	199,875
	1913	253,470	26,320	2,606	1814	94,741	367,658
	1914	256,547	27,608	2696	2071	98,285	387,208

CHAPTER XXI

LOCATION OF ELECTRIC INTERURBAN RAILWAYS

Development of Electric Interurban Railways. Electric traction was inaugurated in the latter part of the last century and developed with marvelous rapidity in the succeeding years, although it was not until the first years of the present century that the building of electric interurban lines became general. The first lines built frequently followed the public highway, and adopted curves and gradients that precluded their entering into the general competitive field of railway transportation. More recently constructed lines, however, have undertaken to purchase their own right of way, to build their own roadbed and bridges, to use gradients and curves that will permit high speed and heavy hauling, and as a consequence have become real factors in the transportation scheme of the country. In late years, freight, baggage, express and mail are carried by some lines, and well-equipped passenger coaches, including sleeping cars, are now in use on several interurban railroads.

Character of Traffic. Up to the present time, the traffic on electric interurban railways has been chiefly passenger travel, and it is probable that in the future the greatest usefulness of this class of railways will be found in this connection. However, freight and express may doubtless be carried under certain conditions with profit. At the present time, about 8 to 10 per cent of the gross revenues of electric interurban railroads are derived from transportation other than passenger. For the most part, the service has been local in its nature, although the more extensive interurban systems are operating through trains with stops every ten to fifteen miles in addition to the local trains, which make stops about every two miles.

The passenger traffic is drawn from the larger cities which constitute the terminals in a way, from the intermediate smaller towns and from the rural regions along the right of way. Owing to the small loss of time involved in a stop due to rapid deceleration and acceleration, and to the low cost of stops generally, points for admitting and discharging passengers may be established at frequent intervals. The farming population can be counted on to patronize the road for perhaps two miles on either side of the right of way under normal conditions, i.e., unless some barrier such as a large stream or a steep hill prevents. To a great extent the character of the towns will indicate the thrift and degree of prosperity of the tributary farming districts. The local traffic between the towns and the country regions will be that which results chiefly from shopping in town and the marketing of small produce.

From a study of interurban traffic resulting from a number of years of intimate experience in this connection, Mr. L. E. Fischer states the following three principles for interurban railroads serving " normal territory": *

1. The length of the road and the amount of operating revenue (per mile) have no direct relation to each other.

2. The size of primary terminals has no material effect upon the amount of operating revenue.

3. Approximately, the operating revenue varies directly with the aggregate of the intermediate town and village population.

Electric interurban railways serve chiefly the needs that arise from the commercial relations that exist between a city or a town and its tributary population. In the case of a large city with wholesale mercantile establishments, this tributary population consists of the smaller towns surrounding it as well as the adjacent rural population, and for smaller towns the tributary population consists of that in the nearby rural regions.

Effect of Motor Vehicles on Traffic. In future years, as the public highways become more and more improved, the automobile is destined to compete seriously for much of the short haul traffic that is being taken care of at present by the interurban. The greater comfort and convenience of the automobile make it a very attractive mode of transportation. However, for the longer rides, the automobile can scarcely compete on a strictly economic basis with the electric interurban railway. The initial investment is high and the rate of depreciation rapid, and the mileage covered per day is not large, even by auto-stages that are supposed to be in continuous use, and it is much less for privately owned cars. The fixed charges on a $1000 automobile amount to about 60 cents per day, and these fixed charges are almost independent of the amount of use made of the machine; repairs amount to probably 15 cents per day additional. Private cars are run probably 15 miles per day on the average, and regular auto-stages perhaps 50 miles. This would make 5 cents per mile for these charges alone for privately owned cars, and the cost of fuel, oil, and incidentals would probably add from 3 to 4 cents more per mile, making a total of about 9 cents per car-mile as the lowest estimate that could be expected for riding in a private car. The average number of passengers in such a car would not be more than three, resulting in a cost of 3 cents per passenger mile as the lowest possible estimate. For auto-stages, the cost would be somewhat less owing to the greater mileage made, but owing to greatly increased repair charges the cost would not be much lower. As a matter of fact, auto-stages commonly charge rates that amount to 5 to 10 cents per passenger-mile. Automobiles that do a regular transportation business should be taxed additionally to defray the expense incurred in the extra maintenance of the highways used, and such taxation would add to the cost of this mode of transportation.

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* " Economics of Interurban Railways," p. 25.

While automobiles cannot be made under present conditions to compete economically with the electric interurban, nevertheless they are carrying a considerable portion of the short-haul travel that formerly was taken care of by the interurban railways. This condition results from the added convenience and comfort incident to this mode of travel.

Rolling Stock. Since the traffic of interurban lines is now and probably will continue to be composed chiefly of passenger transportation, it is essential that the cars should be attractive, comfortable and commodious. The usual type of car is similar to the steam-road passenger coach, but is of much lighter construction. The following dimensions and properties are typical of the ordinary interurban car:

Length over all	53 ft. 3½ ins.
Length over body	48 ft. 5 ins.
Width over all	9 ft. 10 ins.
Height over all	14 ft. 4 ins.
Weight of trucks	8 tons.
Weight of car complete	40 tons.
Distance between truck centers	32 ft. 6 ins.
Wheel base of truck	7 ft.
Diameter of wheels	36 ins.
Seating capacity	50

Some of the coaches are of the combination coach and baggage or express type, while some are constructed as separate express cars. Since the freight on such lines is chiefly confined to the package class, it is commonly carried in the express cars without special provision for the same.

General Features of Location. The location of electric interurban lines differs from the location of steam roads in several respects:

1. The characteristics of the motive power used are very different. (Cf. Chapters VIII and IX.)

2. The facility with which electric cars pass around curves permits much sharper curves and more curvature to be used with propriety.

3. The light trains, usually consisting of one or two cars, permit much heavier grades to be employed, since the power required can be applied or shut off as the conditions demand.

4. Economy in power is effected by a constant load, although comparatively light, rather than heavy intermittent loads.

5. The principle of momentum grades is more readily adapted to such service than to steam railroad operation, because there is no direct consumption of fuel while coasting and the power can be readily shut off or applied as needed, and because of the lightness of the trains.

6. Because of the above facts, together with the greater facility in braking and in picking up speed, interurban lines can profitably be made to follow the natural topography to a much greater degree than can steam roads.

7. The location should be made with respect chiefly to the needs of local traffic, and with the idea of transporting people to or from *a* town rather than to or from any particular town.

8. Terminal arrangements in the larger cities usually involve the use of local street-car lines, thus permitting the interurban cars to enter the main business district of the city.

9. For various reasons, stops can be made much more conveniently and cheaply than on steam roads, the cost of a stop on an interurban line being perhaps 5 cents for power and an equal amount for lost time, wear of equipment, etc.

10. The power available for the whole line is a constant quantity, depending upon the capacity of the power plant, and the amount of power available for any one train is beyond the control of the crew of that train, depending upon the demands on the power supply by other trains.

11. The initial investment in power plant, transmission lines, etc., is relatively high, making fixed charges correspondingly high, but the cost of operation is relatively low.

As in steam railway location, distance and curvature are of much less importance than steep grades. Since, however, the total quantity of power available at the power house is constant, the train service should be so regulated by the dispatching of the trains at proper intervals to make as nearly as possible a constant draft on the power. By varying the location of meeting points with respect to summits and sags, the trains can be operated so that they will not be all going up grade or accelerating at the same time, but so that some on the up grade will be able to utilize the power released by others on the down grade. Thus meeting points and stops should be arranged so as to permit a maximum number of trains to be operated with a minimum power-plant capacity.

Stops. In general, stops for receiving and discharging passengers can be much more easily and cheaply made on electric than on steam roads. The dead weight requiring acceleration and deceleration is comparatively small, and the braking power and accelerating power are relatively high. On interurban roads, the rate of acceleration is 1 to 1¼ miles per hour per second, and the common rate of deceleration is about 1½ to 2½ miles per hour per second. This rate is about four to five times that of through passenger steam trains and about two to three times that of local steam trains. The usual frequency and length of stops for passenger trains are about as follows:

	Interval between Stops, Miles.	Time of Stop.
Through steam trains	80	5 min.
Express steam trains	20	3 min.
Semi-local steam trains	10	3 min.
Local steam trains	4	2 min.
Suburban steam trains	1	1 min.
Through electric interurban	15	1 min.
Express electric interurban	8	30 sec.
Local electric interurban	0.5	20 sec.
Rapid transit	0.3	10 sec.

The length of stop for electric trains without baggage or express depends upon the rate at which passengers enter and leave the cars. The curves of Fig. 60 are averages taken from observations described by Mr. R. W. Harris * and indicate the time required per passenger for loading and unloading cars. Where no baggage or express is handled, the time of stop need

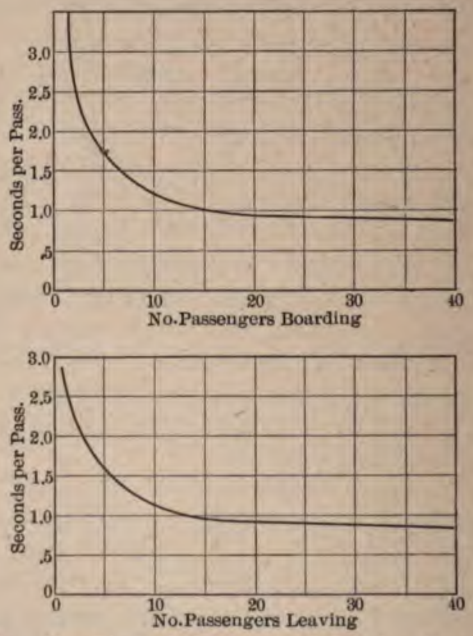

FIG. 60.—Time of Entering and Leaving Cars.

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* Trans. A. I. E. E., 1910.

not be longer than that required for the unloading and receiving of passengers. This time can be reduced by providing larger doorway for exit and entrance.

Traction. The chief characteristics of electric traction have been discussed in another chapter, and brief mention only need be made here of the features of electric traction that are more or less peculiar to interurban railroads. In this kind of service, the motors are invariably on the cars themselves, an arrangement that obviates the necessity of operating a separate electric locomotive. The nominal rating of an electric railway motor is the mechanical output at the car axle, measured in kilowatts, which causes a rise in temperature above the surrounding air not to exceed 90° C. at the commutator after an hour's continuous run at its rated voltage (and frequency, in the case of alternating current motors) on a stand with the motor covers arranged to secure maximum ventilation without external blower. The rating is sometimes expressed in kilowatts and sometimes in horsepower, one horsepower being 0.746 kilowatt. The character of motor required depends upon many factors, among which may be mentioned:

1. Weight and number of cars in train.
2. Diameter of driving wheels.
3. Weight on driving axles.
4. Voltage at the train with power on motors.
5. Desired rate of acceleration.
6. Distances between stations.
7. Duration of station stops.
8. Scheduled speed.
9. Train resistance.
10. Profile and alignment of track.
11. Character of roadbed and track.
12. Frequency of service, involving the time of layover at the end of the runs.

Experiments indicate that for ordinary passenger cars the energy required per passenger-mile is less for trains consisting of six cars or less for electric service than for steam trains. The actual energy used in one series of tests for three distances was as follows, using 53,000-lb. cars and 50 h.p. motors: *

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* "Electric Railway Handbook," A. S. Richey.

determination. The commonly quoted formula desired by Mr. W. J. Davis as applied to interurban trains is

$$R=4+0.13V+\frac{0.003aV^2}{W}[1+0.1(n-1)],$$

R being the train resistance in pounds per ton;
V, the velocity in miles per hour;
W, the total weight of the train in tons;
n, the number of cars in the train;
a, the area of cross-section of a car in square feet.

For ordinary interurban cars with about 100 sq. ft. cross section, this formula becomes

$$R=4+0.13V+\frac{0.3V^2}{W}[1+0.1(n-1)].$$

The University of Illinois experiments * for one 45-ft., 20-ton car, gave

$$R=4\underset{+}{-}0.222V\underset{+}{-}\frac{0.00181aV^2}{W}.$$

Many other formulas have been proposed, but it is not deemed necessary to list them here.

Acceleration. The general principles of acceleration of trains have been studied in a previous chapter. It will be recalled that after a train has been brought up to speed, it has stored in it a certain amount of energy, a portion of which exists by virtue of the translatory motion, and the remainder (about 5 per cent) due to the rotation of the wheels. For electric cars with heavy motors, about 7 to 12 per cent of the total energy is possessed by the rotating wheels and armatures. As indicated previously, the possible rate of acceleration of electric cars is greater than that of steam trains, and in general may be made any rate desired within certain limits. The rate adopted is dependent upon the comfort of the passengers, the character of the equipment and the power available. Rates of acceleration commonly adopted and which represent approximately the most economical rates, are about as follows:

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* Bull. No. 74, Univ. of Ill. Eng. Exp. Sta.

	M.P.H. per Sec.
Steam locomotives, freight service	0.1 to 0.2
Steam locomotives, passenger service	0.2 to 0.5
Electric locomotives, passenger service	0.3 to 0.6
Electric interurban cars	0.8 to 1.3

Gradients. The selection of proper gradients for interurban railways is based on entirely different principles from those governing the choice of grades for steam roads. Electric interurban roads are built mainly for comparatively light trains. The grades have practically no influence on the length of trains nor the number of trains required to carry the traffic. The number and the length of trains are determined entirely by the demands of the traffic and only on very rare occasions, such as picnic excursions, etc., is the traffic ever such as to require more than one train. Even at such times other features of operation limit the length of train rather than the gradient.

The selection of the gradient for interurban roads is based on conditions similar to those existing on light traffic steam railroads. However, in the case of interurban roads, the chief desideratum is the necessary speed over the line, and the attainment of that speed must be balanced against the cost of grade reduction, rather than the operating expenses due to increased train mileage against the cost of construction, as in the case of steam roads. The characteristics of electric motors, see Fig. 15, shows that for either increased tractive effort or greater speed, greater energy must be put into the motor. This indicates that if the power is available on the line, the per cent grade is not a matter of primary concern. Here, therefore, enters another factor, namely, the cost of the power plant. In many cases the choice of gradient may resolve itself into one of relative expense of larger power plant and of reducing the gradient. In most cases, however, the power will be available, and the entire question reduces itself to the relative cost of using more powerful motors on the cars or of reducing the gradient.

The ruling gradient on electric interurban railways does not, therefore, have the same significance as on steam roads, for, the cars being relatively light, the motors can be safely made to exceed their rated capacity for the short time required to ascend such maximum grades without serious heating. Owing to this fact, early interurban lines were frequently built with 8 to 10 per cent grades and with correspondingly sharp curves, but the cost of maintenance and of operation and the safety of operation make such extreme features not permissible. However, grades as high as 2.0 to 2.5 per cent are considered good practice for high-speed service, and in hilly country grades up to 5.0 per cent are frequently used with good results. The discussion in another chapter of rise and fall and of momentum grades is applicable in general to electric railways as well as to steam.

Station stops so far as practicable should be placed on summits in order that the up grade may assist in stopping the train and the down grade assist in starting it. This principle is not always applicable in country lines, but elevated rapid transit lines in cities make use of it to a very great extent, not only accomplishing the above result, but cheapen construction as well by shortening the columns of the elevated structure.

Curvature and Distance. As in the case of gradients, curvature, both in amount and degree, is not so serious an obstacle in general on electric roads as on steam roads, yet certain limits exist in this case as well as in the other. While electric equipment will readily pass around curves of short radius, their presence necessarily limits speed. About the only advantage that electric roads have in using sharp curves lies in the facility with which the cars can be slowed down and accelerated to allow the train to take the curve at low speed. Here again the choice depends upon the relative value of the desired speed and the cost of construction and maintenance. The same principles in regard to speed and curves that were previously discussed apply to interurban operation.

For street railway work curves having only 50 to 100 ft. radius are common, and such curves have been frequently used in interurban construction, but curves on the latter should be of much flatter degree of curve than these. Moreover, curves on interurban roads should be as accurately spiraled and superelevated as on steam lines.

From the nature of the traffic carried, additional distance in an interurban line is not a serious disadvantage, if it serves to secure additional business or to diminish operating expenses.

The general principles in regard to these matters discussed in previous chapters apply here also.

Speed-time Curves. With given conditions of operation, the performance of electric cars can be determined in a manner similar to that used in steam railway calculations. If under given conditions of grade, alignment, speed, etc., the car is able to exert additional tractive effort, the train will be accelerated and if not, it will continue at constant speed, or be retarded, according as the total resistance is equal to or greater than the tractive effort available. Also, when a train has a certain velocity, by virtue of that velocity it is able to coast either up or down grade or on the level. In general, speed-time curves consist of showing the relation between the speed as ordinates and the time required to attain that speed as abscissæ, and include acceleration and coasting and braking curves, the slope of the former being positive and of the latter negative. Distance-time curves usually appear for convenience on the same charts. The acceleration curves consist of straight portions covering the period of controlled motor current and extending to full current, and a curved portion beyond. The coasting or drifting curves are slightly concave upward owing to the variation of train resistance with the speed. The slope of the speed-time curves indicates the rate of change of speed, or the acceleration. The acceleration in feet per second is,

$$a=\frac{32.2}{2000}(P-R-C\pm G)\text{, or changing to miles per hour,}$$

$$A=0.01098(P-R-C\pm G),$$

A being the acceleration in M.P.H. per second;
P, the total tractive effort in pounds per ton;
R, the train resistance in pounds per ton;
C, the curve resistance in pounds per ton;
G, the grade resistance in pounds per ton.

Having given the motor characteristic curves of performance, the tractive effort at any speed may be obtained therefrom. From the relations $V=At$ and $S=\frac{1}{2}At^2$ (S being the distance), the speed-time and space-time curves can be derived, or they can be derived from the relation shown in Chapter XIV, that $t=\frac{103}{F}(V_1-V_0)$. These curves will, of course, have to be worked out in increments, since the force varies with the speed and no definite relationship between the tractive effort and the speed can be stated.

Fig. 62 shows speed-time curves plotted for given conditions and illustrates the principles of their use. These curves are

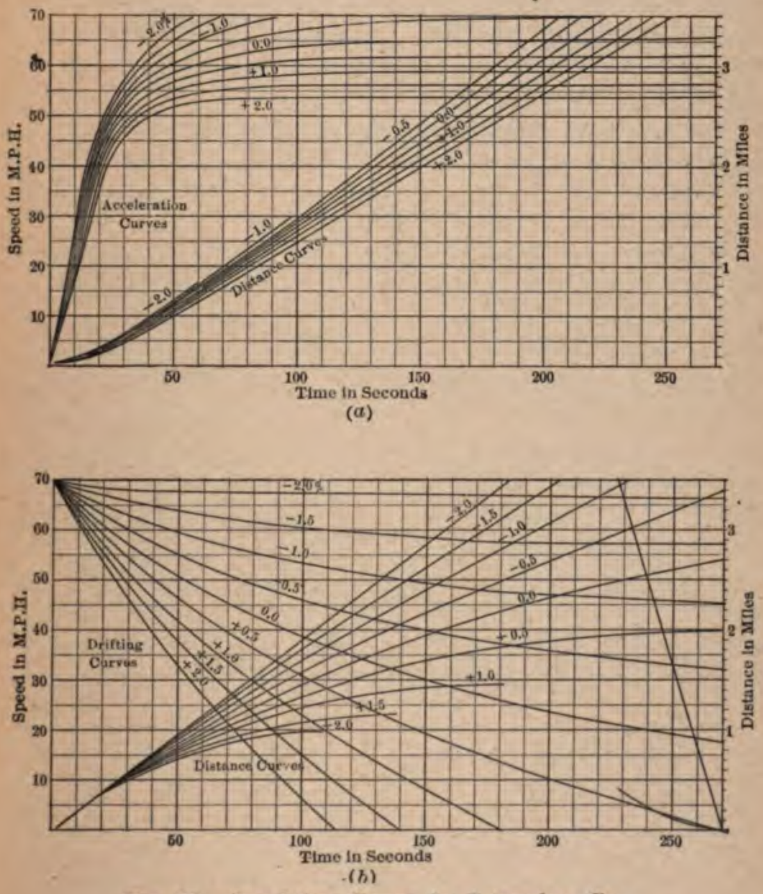

Fig. 62.—Speed-time Curves for Interurban Car.

taken from the excellent article by Mr. C. O. Milloux in the Proceedings of the American Institute of Electrical Engineers, 1902, to which the reader is referred for a more extended discussion of speed-time curves and of graphical methods of constructing the same.

Spacing of Turnouts. In interurban location, the turnouts should be spaced where the cars naturally meet, and hence the length of line between turnouts is a function of the train schedule. Obviously, the time interval between turnouts should be uniform, rather than the actual space interval. Slow speed through villages, up steep grades, etc., should be taken into consideration in the location of turnouts. In general, the number of turnouts will be one less than the number of cars in either direction during the time required to make the run. The best method of locating the turnouts is by plotting the graphical time-table as explained in Chapter XII, and locating the turnouts at the resulting meeting places as shown by the intersection of the lines representing train movements.

Roadway and Track. Right of way for electric interurban railways should not be less, in general, than 40 ft. wide, and should be independent of the public highways so far as practicable. The use of the public highway, which obviates the purchase of a separate right of way, has led many interurbans to follow the highway almost regardless of gradients. However, the private right of way is desirable because of the greater safety of operation and because of increased facility for higher speeds. The roadbed should probably be not less than 14 ft. wide and the cuts should be well drained as for steam railways.

The track should be practically standard construction with a fairly heavy rail, probably 70 to 80 lbs. per yard, and ties not more than 2 ft. on centers. Ballast is desirable, but a great majority of interurban lines have been built with earth ballast.

PART D

PRACTICAL LOCATION SURVEYS

CHAPTER XXII

RECONNAISSANCE

Introduction. No very exact criterion exists for determining whether or not the location of a railroad is properly designed, but the results of operation after construction will in general indicate whether the work was well or poorly done. A bridge is well designed if the members and details are properly proportioned for the stresses that they are to withstand, and if a gross inaccuracy in the design exists a total failure may result. No such exhibition of error in design is noticeable in the case of a railway location, the only exhibition of error being the failure to pay expenses after the line has been put into operation. The trains will run and, to the casual observer, the faults of design do not appear. As pointed out in another chapter, the true criterion of success in location is the realization of the largest percentage of net profits per dollar invested. The statement of Mr. E. H. McHenry, Chf. Engr., Northern Pacific R. R., that "Engineering is the art (or science) of making the dollar earn the most interest,"* applies with peculiar aptness to railway location.

It must be borne in mind that it is not the object of the engineer to make *a* location, but to secure *the* location, that is, the best line possible so that no subsequent line can be built to serve the same territory with more favorable grades, more satisfactory alignment, and at less cost. The line chosen should not only serve the country traversed, but so far as possible the location should block the construction of a successful rival line.

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* Rules and Instructions, Nor. Pac. Ry., E. H. McHenry.

After thus recalling to mind the objects to be attained in locating a railroad, it may be stated that many of the most serious errors arise in reconnaissance. For the most part, the termini of the railroad and many of the intermediate traffic points will be selected by someone other than the engineer, based chiefly on considerations of the probable flow of traffic, and it will usually remain for the engineer to determine the location of stations and yards in the cities constituting the termini and to select the route between them. However, the question whether to build or not to build is frequently decided by the results of the reconnaissance, which ought to reveal whether a line at all is practicable between the points designated, and to indicate generally the possible gradient within rather wide limits. An understanding of the principles of the foregoing chapters is essential to an intelligent undertaking of a reconnaissance.

Mr. Wellington very aptly stated that reconnaissance is an art rather than a science, the latter being capable of determination by well-established laws, while the former (art) is a treatment of each case according to one's judgment, largely influenced by the action of others under similar circumstances. A matter that admits of scientific treatment must be susceptible of rigorous analysis. For example, given the conditions of traffic and topography, the effect of increasing the ruling gradient can be scientifically analyzed, but the proper running of a transit line, pitching camp, or keeping notes cannot. The former is a science while the latter are arts. So, likewise, the method of reconnaissance by riding horseback over a wide strip of country, noting the drainage and the possibilities of location that it contains, is an art.

A Study of Areas. Reconnaissance consists essentially of a study of areas or strips of territory rather than of surveyed lines. The entire range of country between the points to be reached must be passed over and made familiar.

"Thus in reconnoitering a proposed line, *AB*, supposed to be about 100 miles long, we may reasonably take the valley line to the right, or the town *C* to the left, as the lateral limits, but nothing less than this, and the whole area between them should be studied as an area, and a topographical map in the mind's eye made of it all; exact comparative knowledge of all the various passes and other governing points being obtained on reconnaissance, or by subsequent survey or spur lines.

"This single rule is one rarely thought of or acted upon until repeated blunders have enforced it. Error is particularly liable to follow from neglecting it. . . . We may *survey* lines, but we must never reconnoiter them. If we do it is not reconnaissance." Wellington's "Economic Theory of Railway Location," p. 835.

Prepossessions in favor of any particular line or route must not be retained too tenaciously, but the area studied should be examined with an open mind. Likewise, too hastily drawn conclusions, either for or against any particular route, must be avoided.

Passes or *gaps* are usually found where the headwaters of two streams on opposite sides of the divide that separates them leave the crest of the divide. Frequently the indentations in the ridge alternate on the two sides so that one lies by the other with a ridge between, in which case a saddle or low place can best be found by riding along this ridge. Sometimes overlaps of hills obscure passes in such a manner as to make the ridge appear solid without a break in a distant view, and only a close examination will reveal the valleys that cut into the ridge. It may happen, of course, that a tunnel from a valley on one side to a valley on the other is the only practicable mode of crossing the ridge.

Controlling Points. Certain topographic features such as passes over a mountain range or over even a lower divide, and suitable places for bridging large streams, frequently exercise a controlling influence on a railroad location. In the United States, the excellent maps of the U. S. Geological Survey, which are readily available, are indispensable for searching for passes and breaks in ridges. Sometimes a scheme of coloring a contoured map, preferably in brown, using deeper shades for the higher altitudes, will render breaks and low points in a range of hills more readily discernible.

In crossing a river that has comparatively high bluffs on either side, it is necessary to find an easy descent to the river bottom by following down a side inlet stream, and after crossing the river to find a gradual ascent on the opposite bluff by following the side drainage again. A number of examples of this feature of location may be noticed in the location of those railroads that cross the Mississippi River.

As an example of a river crossing exerting an influence on location, the case of the Thebes bridge over the Mississippi may be cited, where a number of railroads converge to take advantage of a structure already built and the only one in that region.

Where a tunnel is to be driven through a ridge, some time can be profitably spent in seeking the thinnest portion of the ridge through which to drive the tunnel. Saving 100 ft. of tunnel length would repay the expenses of a surveying party for perhaps three months' search for the shortest bore.

Relation of Location to Drainage. The natural drainage slopes are all important in the projection of a railroad. As Mr. D. W. Washburn, locating engineer for the Gould lines in the Southwest, once said to a group of assistant engineers, "First get into your head the drainage, *drainage*, DRAINAGE. The direction and location of the drainage is the framework on which you must hang your location." The principal streams, their nature and rate of fall, the location, direction and slope of the principal tributaries, must be familiarly fixed in the engineer's mind. One has but to glance casually at the railroad map of the United States west of the Missouri River to see how the Union Pacific, the Burlington, the Santa Fe and other railroads follow along the slopes formed by the various streams. The general fall of the country may be estimated from the character of the streams. Below are given the rates of fall of a number of streams that are more or less typical.

	Feet per Mile.
Upper Mississippi, above St. Paul	20
Lower Mississippi below Keokuk	0.4
Lower Mississippi below Memphis	0.1
Illinois	0.4
Missouri (lower)	1
Missouri (upper)	10–30
Ohio below Pittsburg	0.4
Arkansas above Pueblo	34
Arkansas below Pueblo	0.5
Green River (Ky.)	0.4
Red River	0.14–5.0

It is useless, of course, to undertake to project a line of a certain character through a country that will not yield such a line. To attempt to build a 0.5 per cent grade line through a 1.5 per cent country will but lead to disappointment, and the engineer's judgment should be such as to enable him to discern readily about what a country will yield in the way of a location by examination in the reconnaissance.

Ridge vs. Valley Location. Much has been written and said in favor or one or the other of ridge or valley locations, but the reader does not need to observe very widely to note that almost any railroad of considerable length is located by a combination of the these two types of routes. The crest of a ridge with easy slopes in either direction makes easy shifting of the line to one side or the other in order to secure a uniform and desirable gradient. Other arguments in favor of a ridge line are (1) freedom from dangers of overflow from streams, (2) few bridges because the line will not have to cross and recross the main stream as well as the tributaries, and (3) the grade can be more easily adjusted to a predetermined rate ordinarily because of the greater effect on elevation of a short shift of the line. Some of the advantages of the valley location are (1) grading will cost less because the material encountered can be more easily moved due to the fact that it is chiefly earth instead of rock, the latter occurring along the top and sides of the hills, (2) usually the curvature is less because valleys are commonly straighter than ridges, (3) towns are more advantageously located in the valleys, and it is from the towns that traffic is derived chiefly, (4) produce from the surrounding country will be hauled downhill to the railroad instead of uphill, and (5) generally a more uniform natural slope will be found in the valley than on the ridge, and the rate of fall of the country will have much to do with the grades that can be obtained.

Rough Country. The transverse slope of valleys is in general that of a segment of an immense ellipse, so that as one approaches hills or mountains, the slopes become gradually steeper. When such an approach is unbroken by deep valleys of minor streams, and is gently rolling or undulatory, to the unpracticed eye it is likely to appear to be easy of access for a railroad. For example, the Colorado and Southern R. R. as it winds around the mesas at the base of the Rocky Mountains has many grades that are about as steep as those occurring on the Union Pacific

R. R. in crossing the mountains. On the other hand, country that appears to be very broken may have a general slope that will enable a very satisfactory gradient to be secured. Heavily wooded land always appears much more forbidding than the same kind of country cleared. One is much more likely to be deceived in regard to slopes and elevations in rolling than in rough country. For these reasons, country that looks rough and forbidding should not be given over, and on the other hand, apparently level plains or easy rolling country should not be taken too lightly, but should be given thorough examination.

Because of the ease of travel and the apparent merits of a route that are largely artificial, engineers are sometimes prone to follow highways to the neglect of better routes. This tendency to error should be guarded against in general, although old trails and wagon roads may occupy the low grade routes. The Atchison, Topeka and Santa Fe R. R. follows in a general way along the old Santa Fe trail, which had served as a traffic course for the Indians for centuries before the road was begun. De Vaca found it three hundred years before the engineers of the Santa Fe, searching for the best location that the country would yield, discovered that the Trail traversed the easiest gradients and the most favorable stream crossings.

Use of Maps. The maps of the U. S. Geological Survey and of the various state geological surveys are so complete, so far as this country is concerned, that much of the time formerly spent in reconnaissance is saved, and a study of these maps with whatever other maps may be available, followed by a rapid riding over the country, will give a more adequate knowledge of the " lay of the land " than an extended reconnaissance would give without the aid of such maps. With the maps now available, the engineer in America should be able to eliminate all but a few possible routes for consideration, and a rapid reconnaissance should eliminate most of these. Under many conditions, a study of maps and a rapid reconnaissance will confine subsequent explorations to only one route.

Equipment and Methods. It is needless in this connection to enter into an extended and detailed description of methods employed in conducting a reconnaissance, a bare outline of instruments used and of approved procedure being deemed sufficient.

For ascertaining elevations, particularly where there is considerable range in the elevation of the country traversed, the aneroid barometer is most useful. It should be borne in mind, however, that the aneroid is only an approximate mode of obtaining elevations, and it should be frequently referred to a standard datum. Numerous books on surveying give instructions for the use of the aneroid, hence nothing of the sort is attempted here. Many engineers use a Locke hand level for reconnaissance. On a location with which the author was connected, a line of levels was carried through very rough country for nearly 25 miles with an error of only about 14 ft. by means of the hand level. However, the chief use of the hand level in this connection perhaps is obtaining the rate of slopes rather than elevations.

Distances can be estimated by timing within a reasonable limit of error. A horse walking through timber on level ground will travel about 3 miles per hour where there is not much underbrush. Over rough ground or through thick woods, the rate would only be about two-thirds as fast. A pedometer that will register the horse's stride will also give a fairly good notion of distances traveled. Horseback riding probably constitutes the most satisfactory mode of traversing rough or wooded country. Army cavalry count on being able to lead a horse wherever a trooper can climb without using his hands.

When the ground is such that it can be covered in a vehicle, an odometer attached to the wheel, or a cyclometer on a bicycle, or a speedometer on an automobile, will indicate very closely the distances traveled.

In more detailed reconnaissance, the stadia with light instruments will be found advantageous. The stadia may be used very satisfactorily where the route has been practically selected beforehand from maps or other sources, and if it is desirable to explore only one route, the stadia will be found to be very convenient.

A pocket-compass for ascertaining courses is a necessity. A prismatic compass that can be closed up and placed in the pocket is the most convenient sort. Such an instrument usually reads to quarter degrees and affords sufficient accuracy for this kind of work.

Notes. The notes that may be taken on a reconnaissance are necessarily crude and frequently almost unintelligible to anyone except to the person who took them. By noting the time of passing points of interest and then recording the time of passing points of fixed location, it is possible to interpolate the positions of the intermediate points with a fair degree of accuracy. The following example, taken from F. Lavis's "Railroad Location Surveys and Estimates," will be of interest. It had been decided to build a line from *A* to *E*, Fig. 63, passing through the towns of *B* and *D*, which were of considerable importance. Between *B* and *D* there was a choice of two routes, the valley route via *C*, a town of importance, and the ridge line via *F* and *G*, two small towns which gave promise of growth. All this was determined from existing maps. Conditions were such that unless about 0.6 per cent grade could be obtained, the line would not pay.

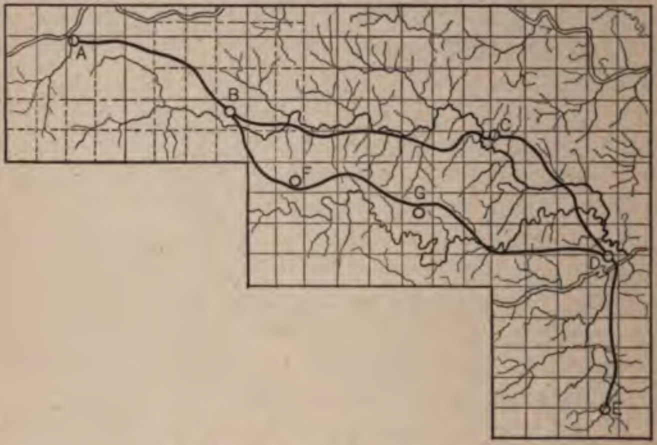

Fig. 63.—Reconnaissance for Route.

"At 6. A.M. the outfit started. Most of the men walked, about one-fourth of them being allowed to ride. Thirty miles over poor roads were covered by 5 P.M., a camping place selected, tents put up and the men eating supper by 7 P.M. The first stake was driven before 8 o'clock the next morning and the work was fairly started." The party was set to work under the direction of the assistant engineer, while the locating engineer made a more careful reconnaissance of that portion of the line assigned him, making the round trip of approximately 120 miles in four days. The trip was made in an open spring wagon; observations with hand level and compass were taken, and a full sketch was made of the highway, showing all branches from it, stream crossings, houses, of which there were few, sketched topography and obtained all the local names that could be learned. By means of the public land survey maps, the notes taken were readily plotted. The line was finally located via *C*, owing to the fact that a 0.6 per cent grade along the ridge line was impracticable.

CHAPTER XXIII

THE PRELIMINARY SURVEY

Purpose of the Preliminary Survey. When, by methods discussed in the preceding chapter, the engineer becomes sufficiently familiar with the country to be traversed by the proposed railroad to enable him to limit his further studies to one or, at most, a few possible routes, he is ready to run the preliminary or trial line. The preliminary survey consists of running one or more carefully stationed angle lines from which a topographic study of the route can be made. While the chief function of the preliminary survey, as used by most engineers of to-day, is to serve as a basis for the topographic map of the route, its usefulness will be greatly enhanced if the preliminary follows as closely the final location as possible, and the skill of the locator will be shown by the nearness to the final location that he can project his preliminary. The information obtained on the preliminary is taken with sufficient accuracy to enable questions of gradient, distance, curvature, clearing, property rights, bridging, tunneling, and classification of materials to be excavated, to be answered with a fair degree of reliability. Grading estimates, however, based on preliminary surveys are of but little value beyond being gross approximations. The purpose of the preliminary is to assist the engineer to find the position of the line that he desires, and it is, in fact, a trial or conjectural position of that line. With the aid of the information that this trial line brings, he is usually able to find *the* line with considerable accuracy.

Organization of the Party. Only physically robust men should be selected to make preliminary and location surveys. Many heavy loads, such as instruments, stakes, etc., have to be carried at a fast speed, and those that are physically unfit will impede the progress of the party. It has been the author's experience that immature boys, under 18 or 20 years, perhaps, are incapable, as a general rule, of doing their portion of the work and maintaining a proper pace all day. With the assumption that the men are physically fit and that those in responsible positions are intellectually capable of performing their duties, a brief outline will be given of the duties that belong normally to each member of the party, although the reader is referred to the various texts on surveying for more complete directions for doing the work.

The organization for a railroad survey may be outlined as shown below.

Locating Engineer
Chief of Party

Transit Party	Level Party	Topography Party	Camp Help
Chief of Party	Levelman	Topographer	Cook
Transitman	Rodman	Assistants (one or more)	Teamster
Head chainman		Draftsman	
Rear chainman			
Stakeman			
Rear flagman			
Axemen			

A party with the above organization should be assigned 50 to 100 miles to cover in making the preliminary surveys.

The *Locating Engineer* usually makes the reconnaissance personally and has general charge of the parties and the entire location. He decides largely the questions of grades, curvature, whether to enter certain minor towns, and other features of the location. He may or may not be in direct personal charge of the surveying parties in the field in making the detailed location.

The *Chief of Party* may be the locating engineer or he may be an assistant engineer in charge of the parties and report to the locating engineer. The chief of party must have had sufficient training and experience to enable him to take general directions from the locating engineer and to get all the information that will be needed in the design of the location. He has charge of the camp and the camp purchases, and has authority to employ and discharge men. His specific duties with respect to the surveys will be to direct the transit party in their selection of line and to study the profile and plot of the line so that he may properly direct the parties. During the first three-fourths of the day, the chief of party is usually ahead of the transit party selecting turning points and in general keeping things moving.

The remainder of the day may be spent in camp studying the line previously run and planning the work for the following day.

The *Transitman* usually ranks next to the chief of party and assumes charge of the party in the absence of the latter. It is his duty to run the transit, keep the transit notes, and to plot, or, at least, to check the plot of the transit line at night. A good transitman will set up his instrument and be " on line " in two or three minutes after arriving at his point. Much depends on the accuracy of his work, hence the transitman should be a careful, reliable person. Hubs and turning points to which the transitman must " move up " have to be lined in with care, but intermediate stakes may be lined in without great precision. Where a point can be set some distance ahead, as in crossing a valley, the stake may be so set and the intervening line run by means of the compass needle with sufficient accuracy, which method is a very great advantage in the event that the valley is heavily timbered, because it avoids the necessity of obtaining a backsight. The author has run lines across valleys in this manner a mile or more wide, missing the far point already set by not more than a foot.

The transitman should never set a transit point ahead without verifying his alignment by checking on his backsight before moving up to the new point. Much trouble will be avoided by observing this simple rule. Setting tacks in transit points by double sighting is another wise precaution, and will frequently prevent " unexplainable " deviations in the line.

To a considerable extent, the speed of the party will depend upon the proficiency of the *Head Chainman*. If he moves forward at a lively pace after setting each stake, keeps well on the line and is careful to do his work accurately, the progress will be rapid, but if he is not proficient in these respects, the progress will be slow. The rear chainman, axman, and stakeman will accept readily the pace set by the head chainman, while they might resent urging from the transitman or chief of the party. Inasmuch as the party organization is essentially the same for location as for preliminary, it is not out of place to state that on the location survey, the head chainman will greatly expedite the work if he readily grasps the amount of the chord and tangent offsets so that he can range himself on the line of a curve without delay. The head chainman is responsible for the accuracy of the chaining. He must see to it that the rear chainman performs his duties properly, that the tape is broken properly in going up or down steep slopes, and that the tape is horizontal whenever a measurement is being taken. He is, in a sense, foreman over the chaining party. He will be better fitted for his duties if he has had some experience in running the instrument, and should, in fact, be able to relieve the transitman should the latter be absent. The head chainman should exercise judgment also in the selection of transit points so as to offer an unobstructed view ahead, as far as practicable, and so that the difficulties of set-up will not be too great.

The *Rear Chainman* should walk ahead of the end of the tape as it is dragged forward in order that it may not be dragged past the point at which it is to be held. He should call " chain " when the end of the tape lacks 3 or 4 ft. of being at the point in order that all adjustments may be done by pulling the chain ahead rather than back, all backward movement being so much lost effort. It is also the duty of the rear chainman to check the accuracy of the numbering of the stakes, and he must keep this in mind as one of his chief functions. Should he be in doubt as to the correct number of any station, he should walk back to the preceding one, or even farther if necessary, in order to make sure. He should take care to keep off the line so as not to obstruct the view of the transitman in giving line.

The duty of the *Stakeman* is to prepare, carry, mark and properly drive the stakes at the desired points. The marking should be written from the top toward the point, and the stake should be driven so that the marks will face back along the line in order that the rear chainman or others walking along the line may read the station numbers conveniently.

The *axmen*, where more than one are required, usually include a front axman and other axmen. The former should be able to keep on line ahead of the head chainman, and his ability to do so will lessen the amount of chopping required. Other axmen are needed in heavy brush.

The *Rear Flagman's* duty is to hold the flag on the point of the backsight, and he must be attentive to and be governed by the transitman's signals. The rear flagman is prone to become inattentive to business because for a considerable portion of the time he is not engaged in giving a backsight. This position requires the least skill, perhaps, of all the party, and yet it demands a certain amount of intelligence in regard to the responsibility of the incumbent. Frequently the rear flagman is dispensed with entirely, reliance being had on a " butterfly," or signal left at the last hub.

The *Levelman* runs the station levels behind the transit party, keeps the level notes, keeps his instrument in adjustment, and generally ranks next to the transitman in authority. At night, the levelman plots the profile of the stations run during the day. He should endeavor to keep up with the transit party so that complete information will be available for the chief of party. The levelman should not only obtain the station levels, but should establish benchmarks about every 10 to 15 stations, and should record the elevation of rock out-crops, height of water in streams and lakes, and keep any other notes that will be of use in classifying materials to be moved or in making estimates of cost.

The *Rodman*, as the name suggests, holds the rod for the levelman, and at night reads off the stations and elevations for the levelman while the latter plots the profile.

The position of *Topographer* is a very important one, and should be filled by a competent person if the topography taken is to be of much value. Mr. S. Whinery states * the qualifications of a topographer as follows: " He must possess a keen eye and good judgment for locality, distance and elevation. If he depends too much on tape line and hand level, and lacks discrimination as to relative importance of topographic features, he will neither be able to keep up with the party nor to do his work satisfactorily. Particularly must he have the ability, naturally or acquired by experience, to judge of the relative importance of the topography he sketches. He must know at a glance, from the general lay of the country, that the final location will hug this hillside closely, and its topography must therefore be taken accurately, while that other will not be touched, and therefore may be sketched with less care." The topographer should obtain a sketch of the transit line ahead of where he is working, showing where angles are turned, so that he will not lose time and take needless topography.

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* Trans. Am. Soc. C. E., Vol. LIV, p. 144.

Usually one or two assistants or chainmen are assigned to the topographer to make measurements and to hold the rod.

A *Draftsman* is sometimes employed, who remains in camp and plots up profiles, topographic notes and transit lines. Accuracy is a more essential requisite for a draftsman in this position than the ability to execute elaborate drawing.

The other persons who are ordinarily necessary include a cook to prepare the meals and a teamster to haul the party, stakes and other equipment, concerning either of whom no special comment is needed in this connection.

Equipment. No specially designed equipment is necessary for a railroad survey, although certain types are best adapted to such work. The transit should be moderately light, should have a full vertical circle, have good definition rather than high magnifying power (20 to 24 being ample), should be furnished with an attached bubble and with stadia wires. The level should have good lenses and a bubble with a radius of about 80 ft., equivalent approximately to 0.1 in. making 20 seconds of arc. Dumpy levels are usually found to be the most satisfactory for this work. The tape (it is assumed that the old chain is no longer used) should be of strong material that will not readily break when pulled with a kink in it. There are at present several tapes on the market that are almost unbreakable in ordinary usage. For all purposes, the Philadelphia rod reading to 0.01 ft. is the most satisfactory. Flag poles should be brightly colored, and not over 7 ft. long, as greater length encourages sighting at the top of a rod that may not be plumb. Extra axes, brush hooks and other accessory apparatus may be needed at times. The equipment required by the several parties is as follows:

Transit Party:
1 transit,
2 range poles or sighting rods,
2 100-ft. steel tapes,
3 chaining plumb bobs,
1 8-lb. sledge and a frost-pin in winter,
Quantity of marking crayons,
Axes.

Level Party:
- 1 wye or dumpy level,
- 1 rod and pin for turns,
- 1 metallic tape,
- 1 hand ax with sheath.

Topography Party:
- Hand level, 50-ft. metallic tape, rod, or
- Stadia transit, tapes, rods, etc., or
- Plane table, tapes, rod, etc.

Designation of Lines. Where several preliminary lines are run, they are designated as "Line *A*," "Line *B*," etc., all of the letters of the alphabet being available for this purpose except *L*, which is reserved for the location line, and *I*, because of its illegibility. Stakes are marked with the letter indicating the line and with the station number, or with the station and plus, thus, $B481+62.5$. One line, commonly the *A* line, is run clear through and subsequent lines are usually diversions or branches of this line, the points where such lines leave and unite with the main line being indicated in the notes by an equation, thus,

$$A563+24.6=C0+00,$$

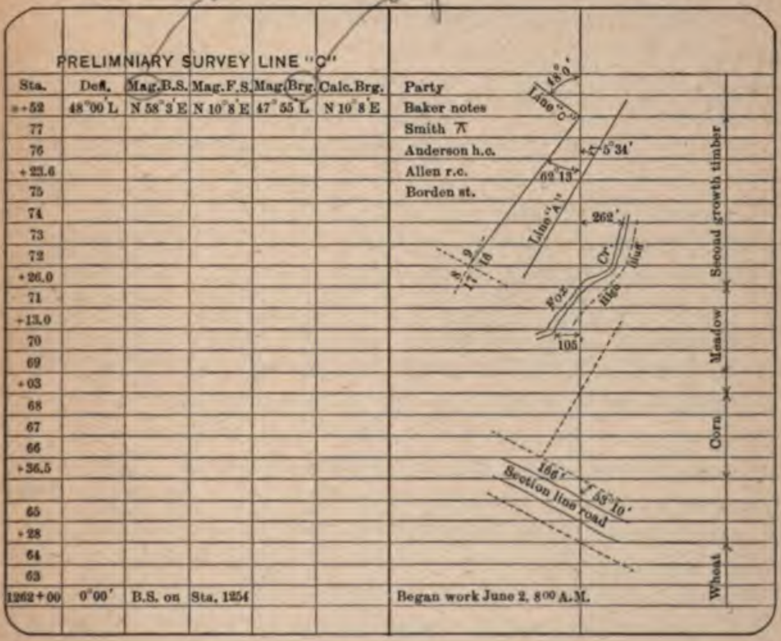
and at the reuniting of the lines,

$$C364+3.5=A972+81.6.$$

Wherever lines cross each other, the station and angle of such intersection should be secured. Station stakes should be driven plumb, with sufficient length projecting from the ground to permit them to be properly marked. Hubs are driven wherever the range of sight requires them, and a witness or guard stake driven 1 ft. to the right of the hub, with the lettering on the side toward the hub, and leaning slightly toward the hub.

Notes. The notes that are kept of the field work should be very complete. An incomplete notation concerning any observation may be misunderstood and hence lead to error. Fig. 64 indicates the appearance of transit notes on preliminary surveys. The transitman should note the time of beginning and quitting work each day, the weather conditions and the personnel of the party. The notes should include station numbers, courses, etc., on the left-hand page and additional notes on the right-hand page showing the location and direction of fence lines, the streams and other natural features encountered, the culture, timber lands, etc., and any other data that may assist in the study of the country. The center line of the right-hand page is taken as the transit line and everything is referred to this line and sketched opposite the proper station on the left-hand page.

out. angle



PRELIMNIARY SURVEY LINE "C"

Sta.	Defl.	Mag.B.S.	Mag.F.S.	Mag.Brg.	Calc.Brg.	Party
+52	48°00′L	N 58°3′E	N 10°8′E	47°55′L	N 10°8′E	Baker notes
77						Smith ⊼
76						Anderson h.c.
+23.6						Allen r.c.
75						Borden st.
74						
73						
72						
+26.0						
71						
+13.0						
70						
69						
+03						
68						
67						
66						
+36.5						
65						
+28						
64						
63						
1262+00	0°00′	B.S. on	Sta. 1254			Began work June 2, 8^{00} A.M.

FIG. 64.—Preliminary Survey Notes,

If the head chainman keeps notes of plusses to fences, streams, etc., he will greatly assist the transitman thereby.

All note books should be numbered in a systematic manner, transit note books being labeled A1, A2, etc., level note books, B1, B2, etc., and topography note books, C1, C2, etc., or in some other convenient way. All books should be indexed on the first three or four pages and this index should be kept up to date at all times. This index is necessarily more of the nature of a table of contents, and for this reason all notes should be indexed alphabetically in special index books. The prevalent use of card indexes is a commendable method. Many engineers, since the introduction of loose-leaf note books, keep their notes in such books, and these notes can then be collected into books according to subjects. A title should be placed on the fly-leaf of each book indicating the general contents of the book, thus

W. & K. V. R. R.
Preliminary Surveys
HOOPESTON TO WATERVILLE
1914
J. L. Wilson, *Transitman*
P. M. Allison, *Chief of party*
R. G. Nutting, *Locating engineer*

Taking Topography. A great diversity of opinion exists among engineers as to the importance of topography, some taking very accurate and complete topography and using it as a basis for the office or paper location to be reproduced accurately on the ground, while others take but scant topography and rely on studying the lay of the ground itself at first hand. The author prefers a mean between these two extremes, taking enough topography to enable a map to be made from which to study the general effect of shifting the line one way or the other, but making no attempt at final location from such a map. To take a great amount of topography is expensive, and even at best is an adequate representation of the ground slopes, classification of materials, etc. On the other hand, a carefully contoured map gives the engineer a perspective that is well-nigh impossible in the field. Mr. Wellington's "Economic Theory of Railway Location" contains a chapter on "Topography: Its Use and Abuse," in which the proper use of topography is very ably discussed and in which this statement appears: "Since the amount of topography ultimately needed and used (when its use is not abused by making it a substitute for the careful placing of the preliminary) can be seen on any location map to be very little, covering a map all over with accurate topography is a sign of weakness and not of strength. On the other hand, accurate topographical lines for a reasonable and moderate distance on each side of the line are an immense assistance for the ready projection of lines, and at points can hardly be dispensed with." In other words, the preliminary should represent the best location that can be projected by a study of the lay of the land unaided by plotted topography, and sufficient topography should be taken with this preliminary as a base to enable comparatively minor improvements to be made in the adjustment of the line to the topography by its use.

Just how far on either side of the line topography should be taken will depend upon the accuracy with which the preliminary is being run chiefly and also on the character of the terrain. The law in Mexico requires that it be taken for two kilometers on either side, which is a futile provision, for the distance should vary with the conditions. Needless to state, the observations made on most of this strip are hastily made and serve only to comply with the legal enactment. No definite rule can be given as to the proper distance to go on either side of the line, for it depends upon so many variable conditions. Perhaps 300 ft. on either side would represent good average practice in ordinary country. Sometimes it may be desirable to contour a certain hill or valley for a quarter of a mile or so in one direction, but such cases are not the ordinary.

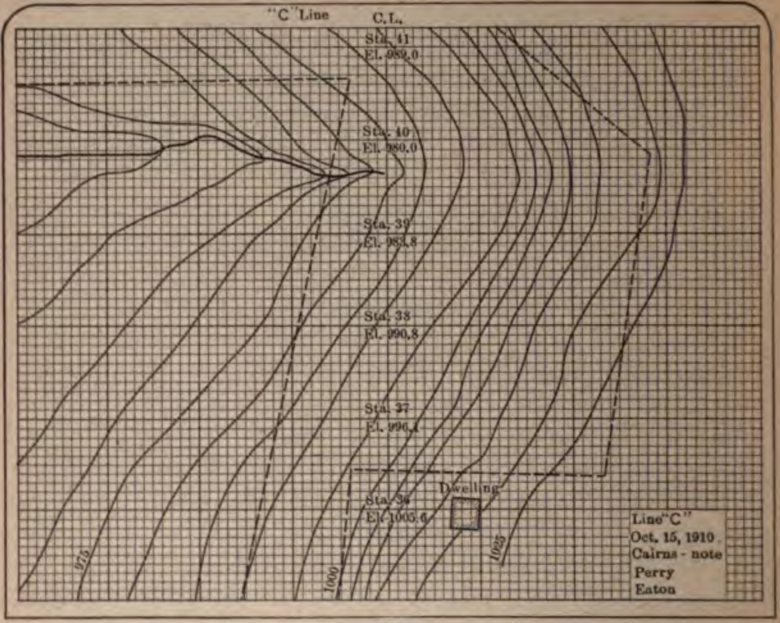
Various methods of taking topography are in use which are described in several texts on surveying and which need not be described here in detail. The chief ones are three in number:

1. The plane table method. Accurate topography can be taken in this manner at a fairly low cost. It has the advantage that the topographical features are sketched in the field while under observation. The disadvantage is that the sheets become torn and are frequently not at hand when needed.

2. The stadia method. Topography can be accurately and rapidly taken in this manner, but it is suited to a wide area rather than to a comparatively narrow strip.

3. Hand level and tape, or by pacing is a convenient and sufficiently accurate method, and the one most generally used. Special topography note books are required for doing the work properly, although the notes are not infrequently taken in a transit note book. Fig. 65(*a*) shows topography notes taken in a special topography note book, and Fig. 65(*b*) shows topography notes on a double page of a transit note book.

Geological Explorations. Topography is a surface expression of the geological structure of the earth beneath much the same

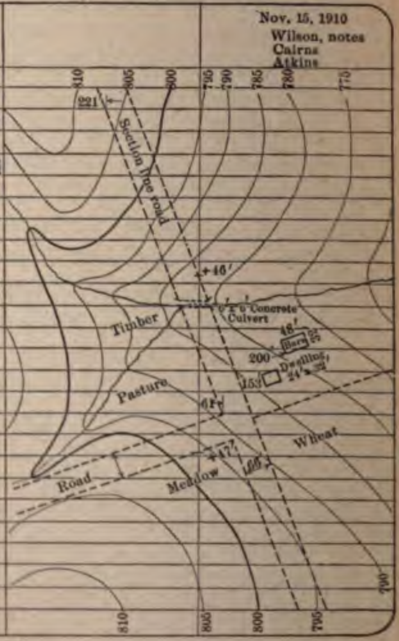


Line "C"
Oct. 15, 1910
Cairns - note
Perry
Eaton

(*a*)

TOPOGRAPHY LINE "B"

STA.	LEFT CONTOURS	CENTER ELEVAT'N	RIGHT CONTOURS
151	[illegible]	795.1	[illegible]
150	[illegible]	793.4	[illegible]
149	[illegible]	788.2	[illegible]
148	[illegible]	785.0	[illegible]
147	[illegible]	782.2	[illegible]
146	[illegible]	785.0	[illegible]
145	[illegible]	787.5	[illegible]
144	[illegible]	794.1	[illegible]
143	[illegible]	799.0	[illegible]
142	[illegible]	802.6	[illegible]
141	[illegible]	804.8	[illegible]
140	[illegible]	806.1	[illegible]



Nov. 15, 1910
Wilson, notes
Cairns
Atkins

(*b*)

FIG. 65.—Topography Notes.

as the outlines of the human body are governed by the anatomical framework. The locating engineer is necessarily concerned with both the topography and the geology, and hence he should make a record of the geological formation as well as of the topographical form of the regions passed over. The control of water courses, drainage, the prevention of sliding of the track and slides of superior slopes on to the track, all make a knowledge of the geological character of the region traversed of very great importance. Successful grading operations are also dependent to a very great extent upon a knowledge of the character of the materials to be found beneath the surface, and the entire question of foundations hinges on the same consideration. Some of the more important geological items to be noted in this connection are:

1. Conditions conducive to slides, such as steeply inclined underlying clay or shale beds over which water may seep or flow at times.
2. Extensive rock faults, since they greatly influence topography and the probability of future topographical changes.
3. Rock strata, their order and inclination, where open to ready observation.
4. Marsh, swamp, or bog formation over which it might be necessary to place the railroad on an artificial foundation.
5. Muskeg formations, or those rock valleys that are filled with organic material, such as leaves, logs, sticks, moss, peat, etc. Such a formation has practically no supporting power for a roadway.

Maps. Two maps are generally made on preliminary surveys. These are on different scales and are for different purposes. A small scale map, about 5000 ft. to the inch, should be made to show the general route and the outstanding features to the general officers of the road and to the public, for use of contractors and for other incidental uses. Great detail, of course, is not desired, only such features as roads, township lines, other railroads, towns, etc., being usually indicated. Fig. 66* shows a portion of such a map, being a portion of the Choctaw, Oklahoma and Gulf R. R. location. A map of this kind serves well as an aid in making progress reports, the amount

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* Methods of Location on the C., O. & G. R. R., F. Lavis, Trans., Am. Soc. C. E., Vol. LIV.

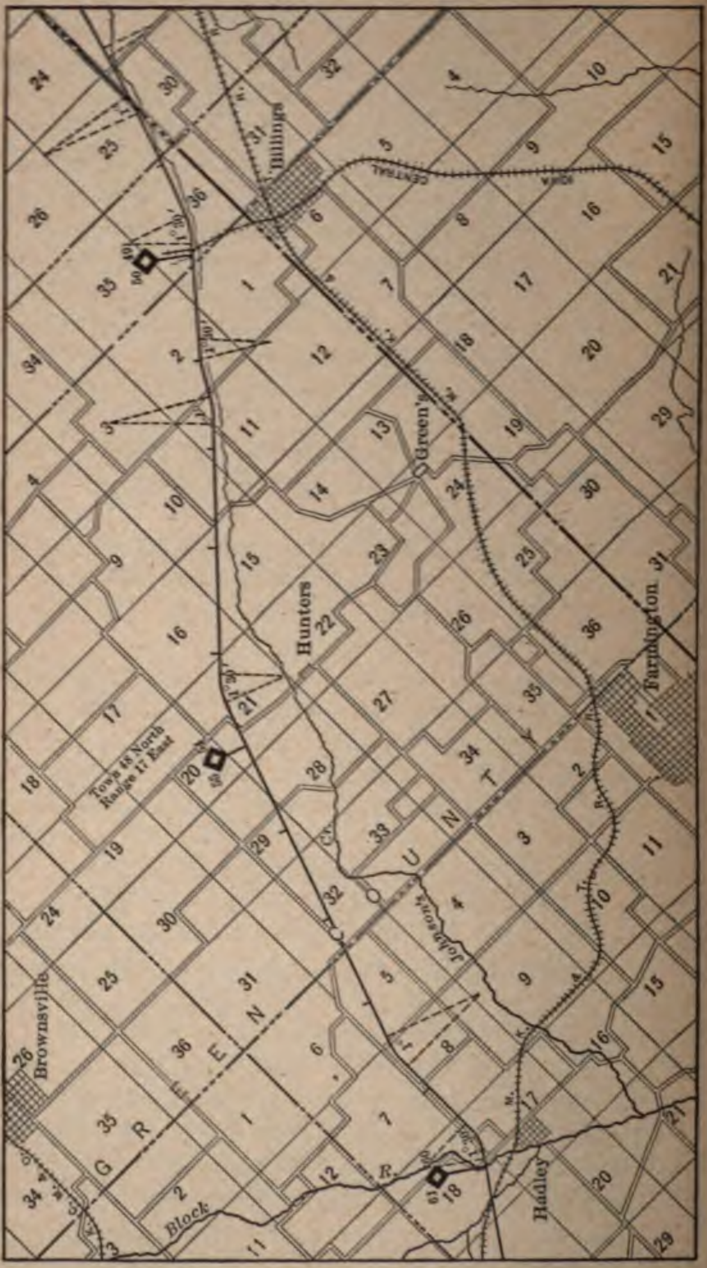
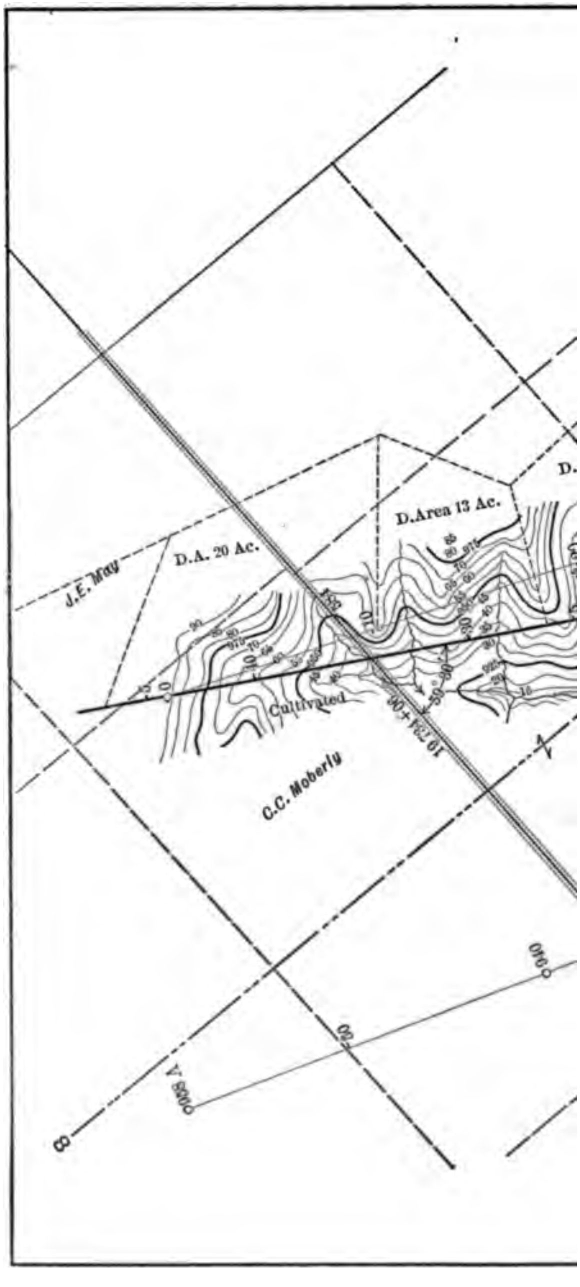


FIG. 66.—Small Scale Map of Location.


J.E. May
D.A. 20 Ac.
D.Area 13 Ac.
D.
975
910
950
Cultivated
C.C. Moberly
10 734+00
8
900
00
940

of work done at any date being marked in colors on blue prints. General features should be indicated for perhaps 1500 ft. on either side of the line on this map.

The detail map should be made to such a scale as is suited to the country traversed. The top of this map should represent the north direction preferable, and if this is not practicable, then it should be the west direction. Both the true and magnetic meridian should be indicated on all maps. While much of the preliminary mapping is plotted to a scale of 100 ft. to the inch, a smaller scale than this, 200 or 400 ft. to the inch, is usually more satisfactory, although a larger scale of perhaps 50 ft. to the inch may be desirable at times. Five-foot contour interval is sufficiently accurate and the scale of the map should be governed largely by the ability to show such contours with clearness. Land lines and ownership, township lines, section lines, and other political divisions should be shown on this map. If such a map is kept rolled, it permits the engineer to make a study of any portion of the line that he may need to examine. Some engineers prefer to plot the map on small separate sheets and then thumb tack them together on a table, but at best this is an awkward procedure. Fig. 67* shows a typical detail map such as described above, being of section of the map made in the location of the Choctaw, Oklahoma and Gulf R. R.

Two methods are in common use for plotting the preliminary line, viz., (1) by laying off the calculated bearings from a meridian or a chosen course and transferring the line to the proper intersection point by means of triangles or a parallel ruler and (2) by plotting latitudes and departures as co-ordinates. Perhaps the former is the more rapid and less fatiguing, although the use of traverse tables or calculating machines will make the latter method rapid and easy. It can be used at least as a valuable check on the former method. Plotting by laying off each tangent from the preceding one is not a satisfactory method, because errors of plotting are cumulative.

The maps should be made on a very good quality of paper, since they will be subject to many erasures and much wear. A tough manila paper is commonly used, and if slightly tinted will be found to be less tiring on the eyes of the draftsman. The preliminary lines are inked in red and the located line in black.

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* F. Lairs, loc. cit.

Brown ink is desirable for contours, while other topographic features are inked in black. Topography not actually taken in the field, but which may be supplied from rough observations or from other sources, should be dotted instead of full lines.

The Profile. After the level notes have been checked by balancing the backsights and foresights, the profile should be plotted. The preliminary profile should be kept up to date by the levelman working at night, the notes being read off by the rodman. Plate A profile paper (1 in. = 20 ft. vertical and 1 in. = 400 ft. horizontal) will be found most convenient. An even 100 ft. should be placed on the heavy horizontal line and the profile begun accordingly. When using transparent profile paper, it may be found advantageous to work on the reverse side so that erasures will not injure or obliterate the engraved lines. All elevations of high-water marks, rock outcrops, lake and pond levels, classification of grading materials, etc., are plotted and labeled. The names of streams should be written vertically above the crossing of the stream on the profile. The type of bridge to be constructed should be indicated and plotted on the profile showing the space occupied.

After the profile has been plotted, the locating engineer makes a study of it by stretching a fine thread along it as a possible grade line in such a position that the cuts and fills will approximately balance, or better, so that the cuts will be about 15 per cent more than the fills. The line should be projected high rather than low owing to the greater ease of maintaining track on a fill than in a cut. Changes in grade should be adjusted by means of vertical curves. The rate of the projected grade should be taken only to tenths in general, except where compensation is made for curvature, in which case hundredths may be used, although it is not usually necessary even there.

After the profile has been completed for the projected location, with all construction features indicated, the locating engineer should walk over the line with the profile in hand and study the situation in the field with regard to the construction as planned. Much money may be saved by so doing, for the engineer may see places where a slight shifting of the line or a change in type of stream crossing will effect marked economy.

A rough estimate of the earthwork on the basis of level sections can be rapidly made by reading center heights and referring to a table of quantities for level sections; or even more conveniently by constructing a special scale which reads in cubic yards per 100-ft. station when applied to the profile. This scheme avoids reading the profile and looking in the table of quantities.

Paper Location. With the topography all plotted on the detail map, the locating engineer projects the location, or makes the *paper location*, on the map by stretching a fine black thread along the proposed route and shifting it back and forth by means of pins stuck in the paper at intersection points, as the contours may indicate the position of the best location. This is done from time to time as the work progresses whenever the topography is complete for a stretch of country of sufficient length to admit of a proper adjustment of grades. The amount of study that can be put on a map at this stage is almost unlimited, but the lack of detailed accuracy may render questionable a too minute projection on such a map. To attempt to reproduce a paper location in the field, while not an impossible task, is not justifiable because of the fact that the line can almost always be improved by making slight alterations in the field. Railroads have been located by an engineer in a central office who was not familiar with the country to be traversed, but such practice is not to be commended. When the paper location has been finally decided upon, it can be inked in and a profile taken off, if desired. The paper location is an additional preliminary line and should be treated as such.

Conventional Signs. In the making of railroad maps, an approved form of conventional signs should be employed. Figs. 68 to 75 show the conventional signs adopted by the American Railway Engineering Association, and for the sake of uniformity, should be generally used for this purpose.

Camp Organization and Sanitation. The efficiency of surveying parties will be dependent to a considerable extent upon the comfortableness of their living quarters. Equipment should be selected so far as possible so as to fold into a minimum space. Tables, cots, camp stools, etc., should be of a folding type. Each man's personal baggage should be practically limited to what he can pack in a suit case. A light camp stove should be provided for a party of considerable size. Midday lunches are eaten in the field, hence lunch boxes that can be attached to a man's belt and be folded when empty should be provided. For many practical suggestions in regard to details of camp equipment, the reader is referred to F. Lavis' "Railroad Location Surveys and Estimates."

A word should be said in this connection concerning camp sanitation. Some of the dangers of camp life are colds, malaria, typhoid, dysentery, snake bites, bruises and wounds in general. Colds can be largely prevented by keeping the mouth and nostrils cleansed by rinsing with salt water, by not overeating,

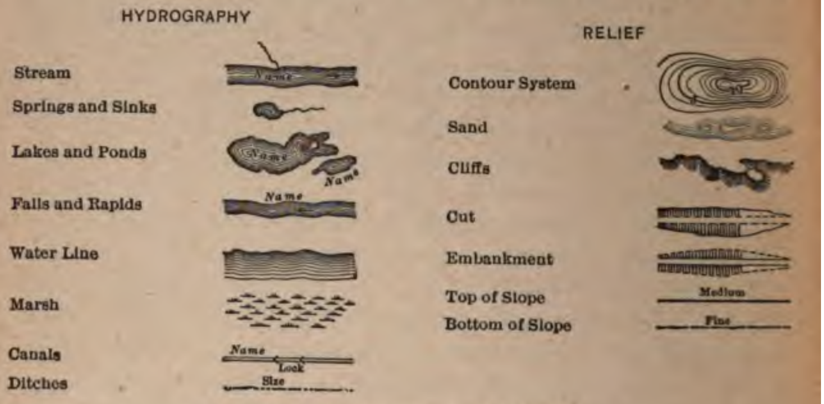

Fig. 68.—Hydrography and Relief.

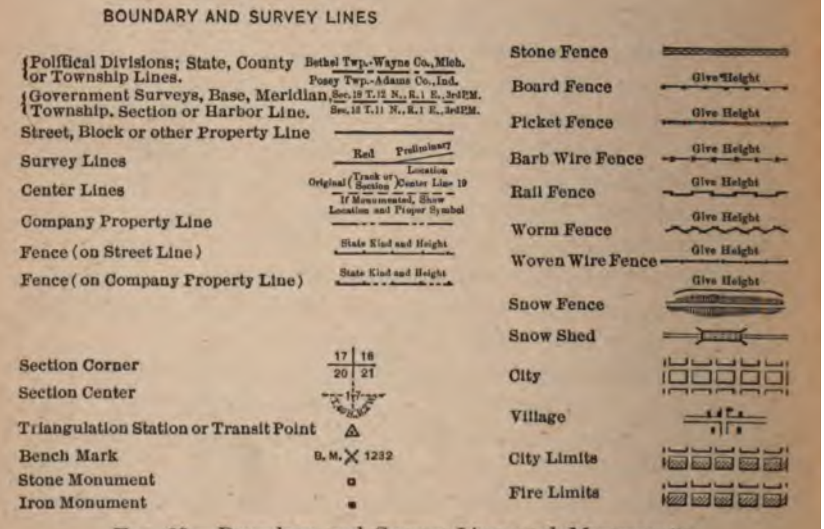
BOUNDARY AND SURVEY LINES
Political Divisions; State, County or Township Lines.
Bethel Twp.-Wayne Co., Mich.
Posey Twp.-Adams Co., Ind.
Government Surveys, Base, Meridian, Township. Section or Harbor Line.
Sec. 18 T. 12 N., R. 1 E., 3rd P.M.
Sec. 18 T. 11 N., R. 1 E., 3rd P.M.
Street, Block or other Property Line
Survey Lines
Red
Preliminary
Location
Center Lines
Original (Track or Section) Center Line 19
If Monumented, Show Location and Proper Symbol
Company Property Line
Fence (on Street Line)
State Kind and Height
Fence (on Company Property Line)
State Kind and Height
Section Corner
17 16
20 21
Section Center
Triangulation Station or Transit Point
Bench Mark
B. M. X 1232
Stone Monument
Iron Monument
Stone Fence
Board Fence
Give Height
Picket Fence
Give Height
Barb Wire Fence
Give Height
Rail Fence
Give Height
Worm Fence
Give Height
Woven Wire Fence
Give Height
Give Height
Snow Fence
Snow Shed
City
Village
City Limits
Fire Limits

Fig. 69.—Boundary and Survey Lines and Monuments.

and by regularity of action of the bowels. Malaria is caused chiefly by the bit of the infected mosquito (anophelines). Its breeding place is stagnant water, and it requires about two weeks for the mosquitò to attain adult stage after being deposited as an egg. The malaria mosquito can be distinguished from the ordinary mosquito (culicines) by its behavior in different stages of its life. It does not travel far from its place of

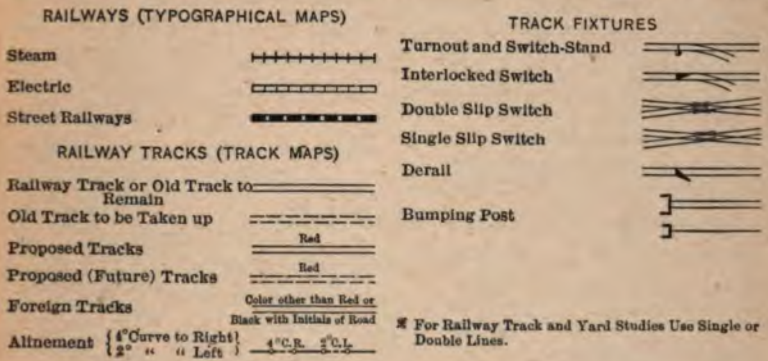
RAILWAYS (TYPOGRAPHICAL MAPS)
Steam
Electric
Street Railways
RAILWAY TRACKS (TRACK MAPS)
Railway Track or Old Track to Remain
Old Track to be Taken up
Proposed Tracks
Red
Proposed (Future) Tracks
Red
Foreign Tracks
Color other than Red or Black with Initials of Road
Alinement {4° Curve to Right} {2° " " Left}
4° C.R. 2° C.L.
TRACK FIXTURES
Turnout and Switch-Stand
Interlocked Switch
Double Slip Switch
Single Slip Switch
Derail
Bumping Post
For Railway Track and Yard Studies Use Single or Double Lines.

Fig. 70.—Tracks and Track Fixtures.

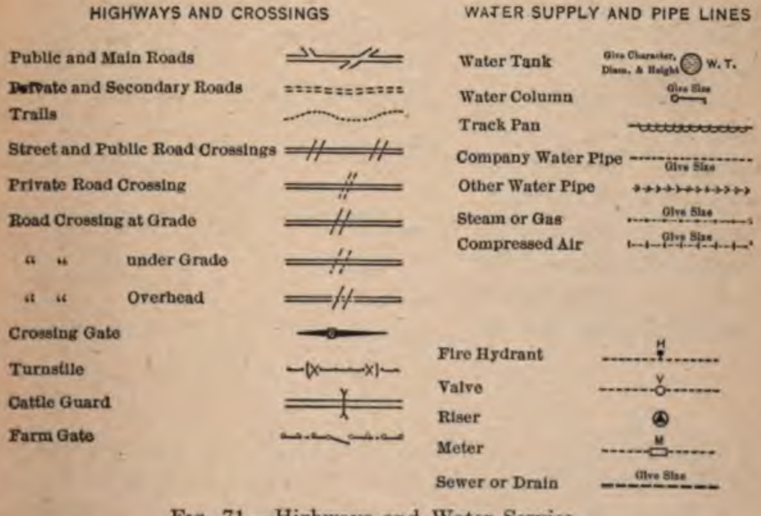

Fig. 71.—Highways and Water Service.

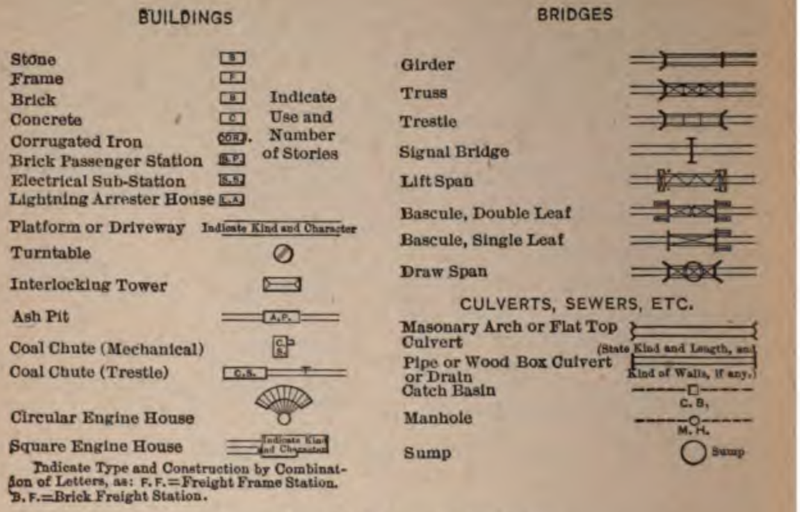

FIG. 72.—Bridges and Buildings.

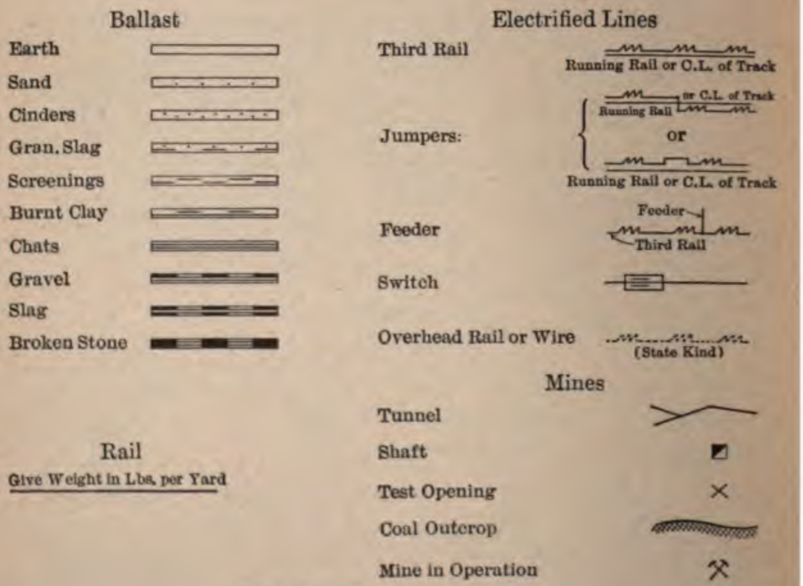

FIG. 73.—Ballast, Rail, Etc.

hatching, hence camp sites should be selected whenever possible some distance (say at least 500 ft.) from stagnant pools, and if that cannot be done, kerosene should be sprayed over such pools or ponds once a week to kill the mosquitos. Typhoid can be prevented almost entirely by inoculation, and all men who are taken into camp should be inoculated before going.

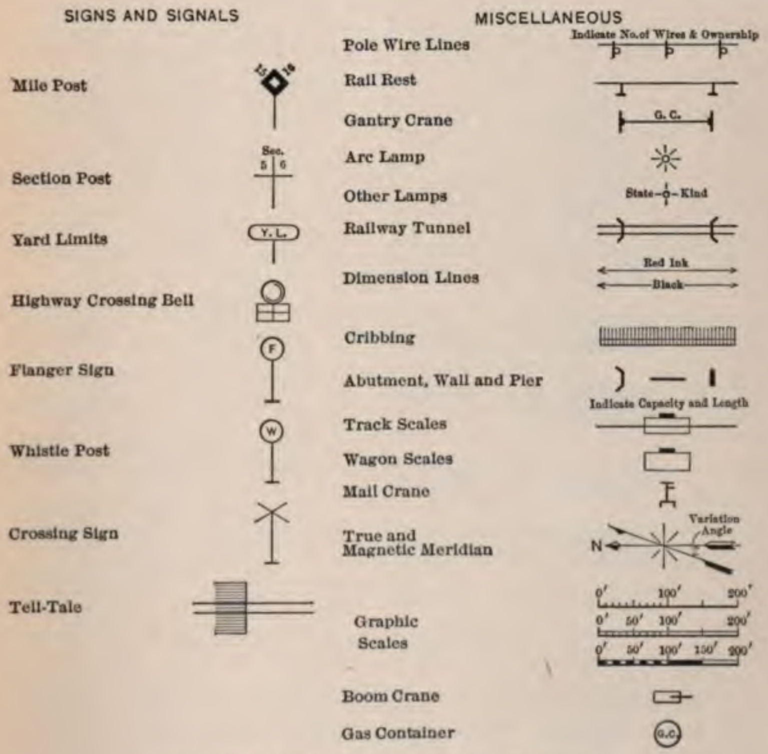

FIG. 74.—Track Signs and Miscellaneous.

Care ought also to be exercised to see to it that the men drink only wholesome water. The best quick and practical test of water is to use only that which is being satisfactorily used by the local inhabitants. Flies should be kept from the food and dishes by all means, by using nettings, screens, fly-traps, fly-paper, etc. The camp should never be within 200 or 300 yards of a barn or manure pile, for flies hatch in such places, developing from deposited egg to adult stage in about two weeks, but do not travel generally more than a few hundred feet from the place where they are hatched, unless carried by the wind. Dysentery is caused largely by improper food and impure water. A well-selected assortment of remedies and bandages should be kept in a medicine chest, properly labeled and with directions attached. Drinking liquors and gambling should be strictly prohibited, for nothing else will demoralize a party of men more quickly than these. A careful looking after these details will be amply repaid in increased efficiency of the members of the party.

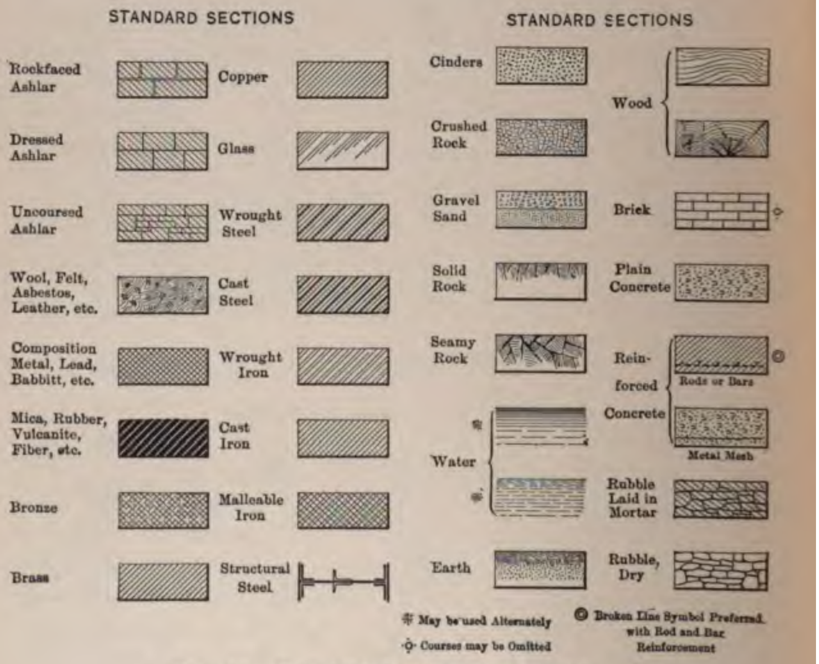

FIG. 75.—Standard Sections of Materials.

CHAPTER XXIV

THE LOCATION SURVEY

Province of the Location Survey. The location survey constitutes the final adjustment of the projected line to the topography. The tangents are carefully joined by curves so that the center line will lie in the same vertical plane with the center line of the finished track. The center line thus laid out serves as a guide for constructing embankments and excavations, bridges, etc. The location survey consists usually in modifying or changing to a greater or less extent one of the preliminary lines in accordance with the information obtained through the preliminary surveys, so that an alignment and profile will be secured that will enable the estimated traffic to be transported most economically. The reconnaissance and preliminary surveys and a study of the topographical maps and the profiles obtained therefrom should give to the locating engineer all necessary information concerning the length of line and the cost of any possible shortening, the most practicable gradients and the approximate cost of any reduction of the ruling gradient, the amount of curvature and the degree of curves, and all other facts required in the details of the location. Having in mind the cost of conducting transportation as affected by grades, distance and curves as discussed in the preceding chapters, the province of the engineer in the location survey is to select the line and profile that the character and amount of traffic will justify.

If the preliminary has been run with skill, the location line should lie upon the preliminary, or approximately so, in easy country. In developing along hillsides and in rough country, the location may deviate to a considerable extent from any of the preliminary surveys. Indeed, it is not at all necessary that the preliminary should be entirely completed for the entire line before the location survey is begun, but the latter may follow advantageously closely behind the former. However, this should not be done until all the information affecting the stretch of line between the controlling points of alignment and elevation is complete, in order that the choice of line for that section may be final.

Since much of the detail of fitting the line to the topography consists in attaining elevation without excessive grades, a brief discussion of some general types of development may be of value in this connection.

Development. By developing a line is meant inserting or adding distance in order to decrease gradients in surmounting a given elevation. For example, if a summit of 105.6 ft. is to be attained in 1 mile, the result will be a 2.0 per cent grade, but, if by winding back and forth on the side of the slope, by detouring and circling around the hill, or by some other device, the distance can be increased to 2 miles, the grade will be reduced to 1.0 per cent. The process lessens the gradient at the expense of increasing the length of line, an economical procedure under most conditions, as may be concluded from the discussion of the preceding chapters.

Theoretically, by development, almost any summit may be attained, but practically numerous difficulties arise to prevent this in many instances. In developing a line, much curvature is necessarily introduced for which the grades must be compensated, thereby losing effectiveness in the added distance. The value of distance, as has been shown, varies with the amount and character of the traffic to be carried, and consequently the amount that grades can be economically reduced by the device of adding distance, which accomplishes no other purpose, will depend upon the amount and class of traffic, and will be decided by the principles already discussed. For rough country and average conditions of traffic, it may be said, the actual length of line may very properly be 5 to 10 per cent longer than the direct route between points of origin of traffic.

Some of the more common expedients or devices for reducing grades by developing will be briefly described and illustrated in this chapter.

Detours. In slightly rolling country where the general natural slope or fall of the country is steeper than that desired as the ruling gradient, detours may be made to cross a ridge or hollow, as shown diagrammatically in Fig. 76. To the untrained eye, a certain terrain may appear practically level, or even to slope down slightly, while in fact it ascends uniformly at a more rapid rate than the ruling gradient of the railroad. Instead of a long comparatively shallow cut, it may be desirable to detour sufficiently to bring the grade within the prescribed limit.

This sort of location, especially in mountainous regions, gives rise to the familiar "horse shoe" and "mule shoe" curves. The term horse shoe is applied to a continuous curve having a total exterior angle between 90 and 180 degrees, while mule shoe is used to designate a continuous curve with an angle greater than 180 degrees. Industrial roads have been built frequently containing such curves, examples of which are so numerous as to make further illustration unnecessary. Fig. 77 illustrates this type of development as used by the Denver and Rio Grande R. R. in its approach to Marshall Pass.

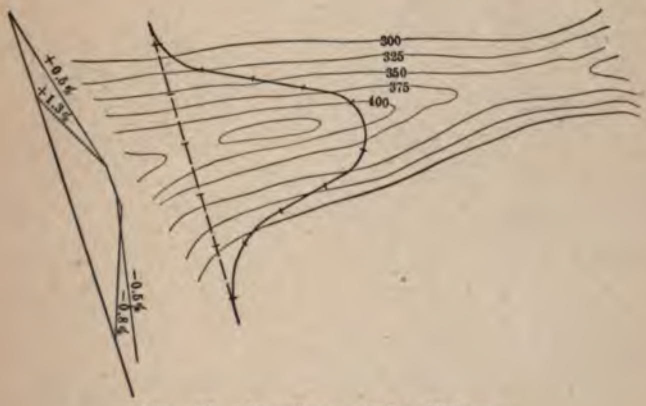

FIG. 76.—Development by Detours.

Zigzag Development. In the location of mountain railroads, the method of ascending a summit by zigzag developing is very common. It consists of doubling or winding back and forth on the side of the slope by turning through half circles where the topography will permit. Fig. 78 shows the approach of the Colorado Midland R. R. to the Hagermann Pass as an illustration of this type of development.

Loops. A rather extreme expedient for development is known as the loop or spiral, in which the line actually doubles back and crosses itself, the difference in the elevations of the track at the crossing representing the amount of vertical climb accomplished by the loop, and nothing more, for where the track crosses over itself there has been no progress in a forward direction. In mountainous regions, particularly in the expensive railroad building in the Alps, loops have been resorted to by engineers to a great extent. Loops may be classified as *bridge loops* and *tunnel loops*. Fig. 79 shows the famous Georgetown Loop of the Colorado and Southern R. R., which was originally built by the Union Pacific. This is a bridge loop, the curve over the trestle being 18° 30′. The track is narrow gauge. Above the loop in approaching Silver Plume occurs an example of zigzag development.

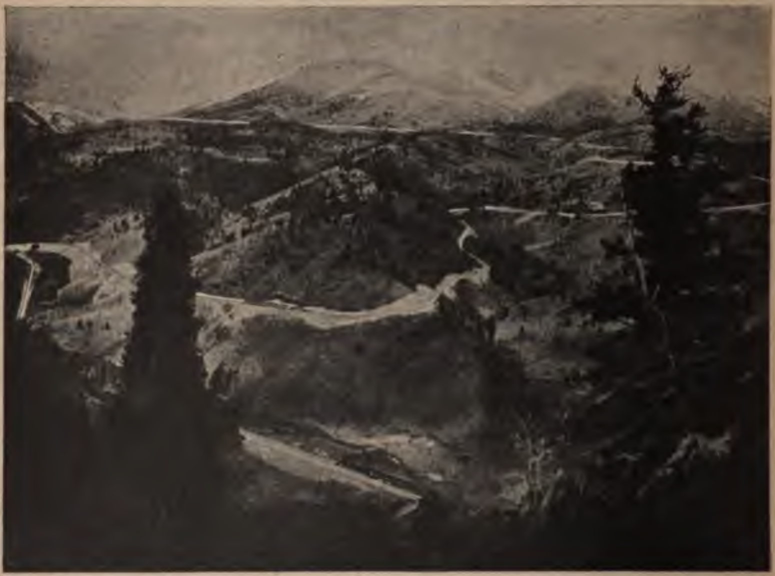

Fig. 77.—Development by Detours on the D. & R. G. R. R. near Marshall Pass.

Fig. 80 shows the Techachapi tunnel loop on the Southern Pacific R. R. north of Mojave, California, located by Mr. Wm. Hood in 1875. The loops of the St. Gothard Ry. in cross-

Gotthard

ing the Alps and those of the Rhaetian Ry. in Switzerland are examples of the use of this developing device in Europe.

Switchbacks. In the construction of mine and lumber railroads, switchbacks may be used to advantage where extremely steep ascents are to be overcome without opportunity for other modes of development. A switchback consists of a break in the continuity of the line, accomplished by an ordinary switch, in passing which the train reverses its direction. Switchbacks usually occur in pairs, so that the train need not proceed far while running backwards. An extreme use of the switchback principle was used in the ascent on the Crown King extension of the Santa Fe R. R. described below:*

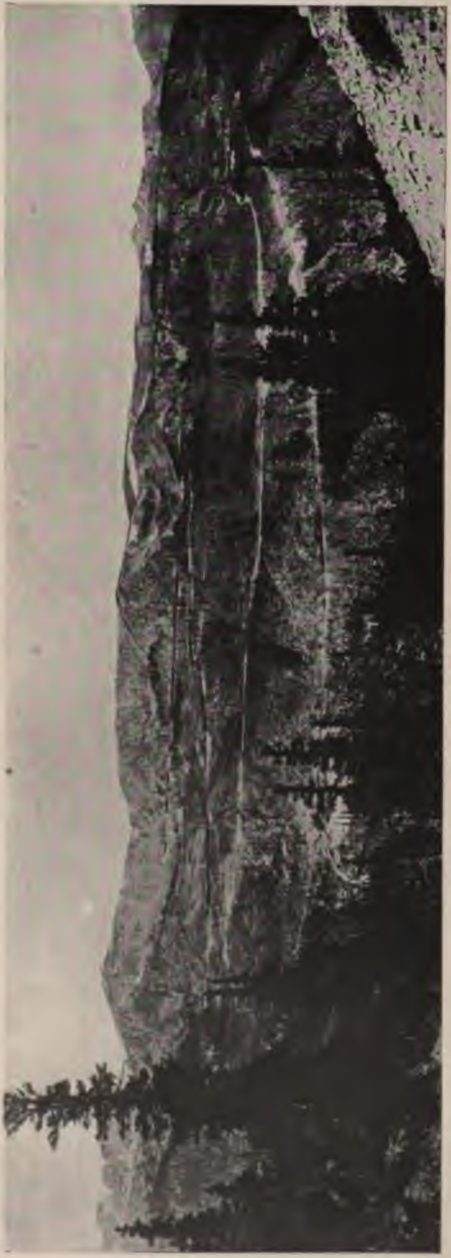

FIG. 78.—Zigzag Development on the Colorado Midland R. R.

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* *Engineering News*, June 2, 1906.

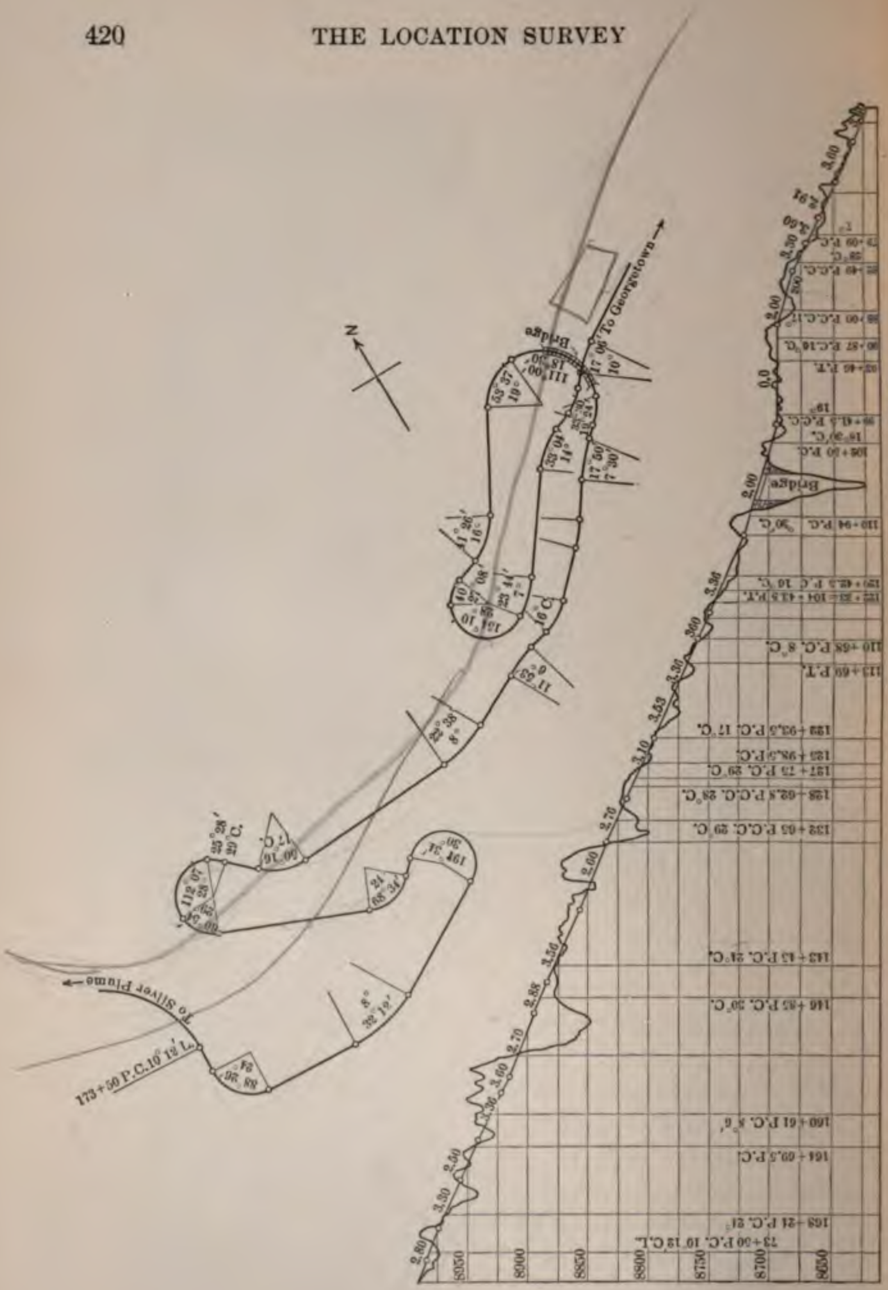

FIG. 79.—Georgetown Loop on the Colorado and Southern R. R.

"The total length of line is 28 miles, and the ascent of 2436 ft. between Turkey Creek and Crown King is accomplished in a distance of 17 miles. There are ten switchbacks with five backup sections of line. These sections are from 1500 to 4000 ft. in length, and have slightly easier grades and curves than the go-ahead sections, in order to give the train a little advantage in backing up. The tails of the back-up sections are at present

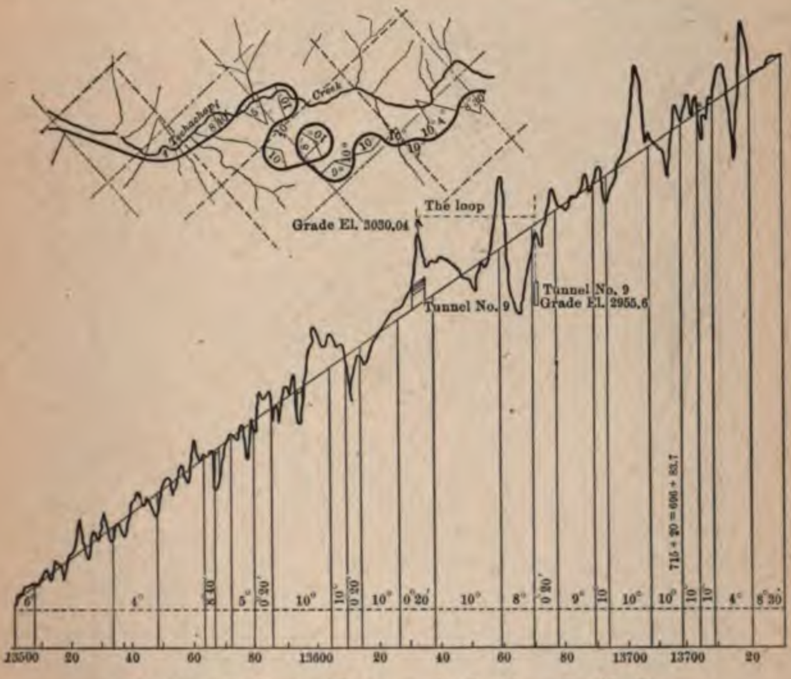

FIG. 80.—Techachapi Loop on the Southern Pacific Ry.

300 ft. long and are continued on a rising grade of 2.0 per cent beyond the switch stands, the maximum grade approaching the switch-stands being 3.5 per cent. The frogs are No. 6½ and No. 9."

An example of the use of the switchback for a temporary line before a tunnel could be built in the case of the Great Northern Railway extension through the Cascade Mountains is illustrated in Fig. 81. Many other examples might be mentioned.

In locating switchbacks, care must be exercised to expedite

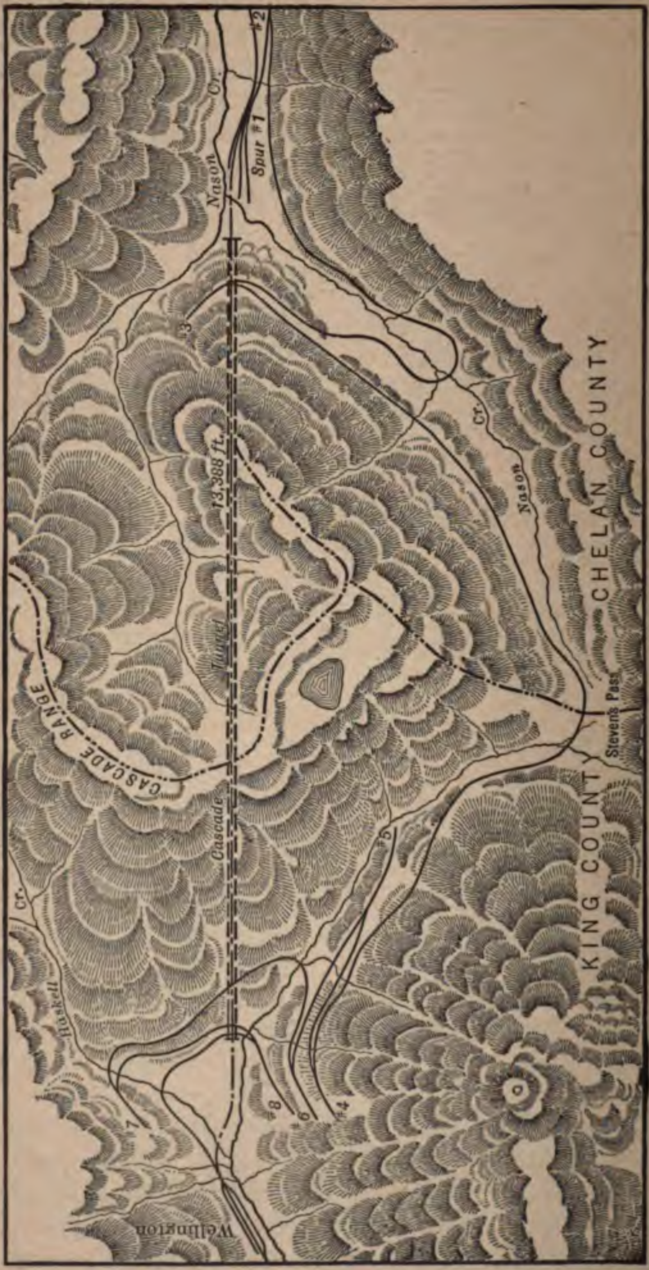

Fig. 81.—Switchbacks on the Gt. Northern Ry.

the operation of trains. The tails of the switches must be long enough to accommodate the longest trains that will pass over the line, and should be given a grade in order to conserve the energy of the train in stopping and allow the same to be expended in starting back.

Supported Line. A supported line is one on which the grade follows very closely the grade contour so that the cuts will make the fills within hauling distance. The term is applied most commonly to the type of location used in rising from the bottom of a valley to the crest of an adjacent ridge or in passing over a ridge in order to avoid a tunnel through the ridge or a deep cut at the summit. Fig. 82 is a typical supported line on the Chihuahua and Pacific R. R. in Adana Cañon. Many other examples might be mentioned, but this one will suffice. A supported line usually involves rather extensive developing, usually of the zigzag character.

Tunneling. The only method of securing a low-grade location in crossing a divide other than developing on both sides is to tunnel through the range. Most ordinary summits over which railroads are projected could be surmounted by developing, but because of the greater cost either of construction or of operation or of both, it is frequently expedient to tunnel instead, and the decision between going over a summit or through it requires careful study of all the conditions, in order that the choice may be wisely made. A preceding paragraph recites the instance of the Northern Pacific Railway using development temporarily where a tunnel was to be the ultimate mode of construction. Even where a summit tunnel is to be built at first, a considerable amount of development is usually necessary before reaching the portal of the tunnel.

Where tunnels are built, there should be no change in grade within the tunnel because of the danger of trains breaking in two in passing a change in grade, and the difficulty of detecting such an accident by the engineman. Where a change in grade is unavoidable, it should be eased off by a long vertical curve.

Cog Roads. In a few instances, peaks have been surmounted by means of a cog or rack rail. The famous Pike's Peak Railroad in Colorado is perhaps the best known example. The Abt system, as it is called, consists of a toothed rail midway between the running rails which is engaged by cogs on a wheel

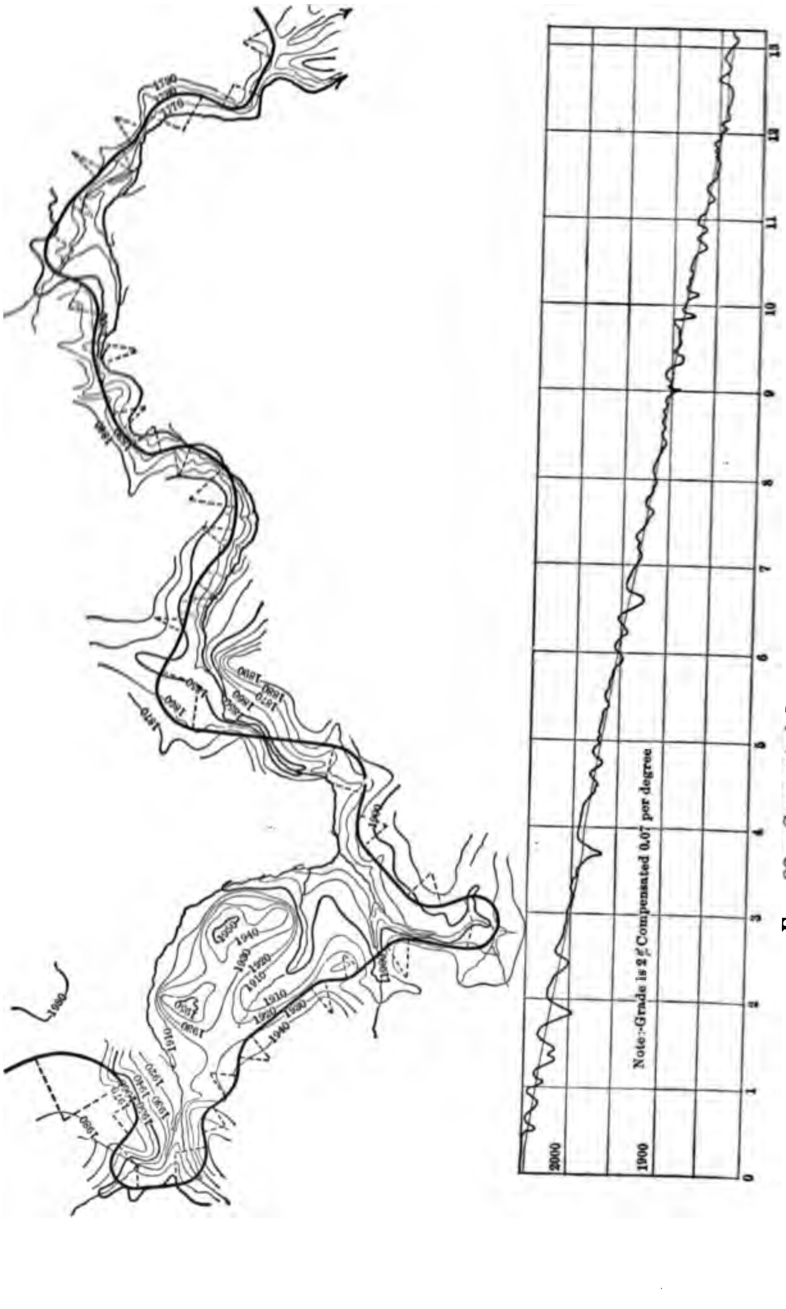

FIG. 82.—Supported Line on the Chihuahua & Pacific R. R.

on the driving axle. The cog road is an expedient to be used only under extreme conditions and can scarcely be said to represent a practical method of crossing a divide.

✓ **Use of the Paper Location.** A wide difference of opinion exists among engineers as to the proper function of the paper location. At best, it is an aid only and should not be held inviolable, and wherever the engineer in the field observes a further possible improvement, he should be free to make it. The most helpful uses of the paper location perhaps consist in studying the effect of "hinging the tangents." i.e., considering one end as fixed and rotating the other, shifting the tangents up or down the hill, and fitting the curves to the topography. In the last, named use of the paper location, a set of rubber or celluloid curves is extremely desirable, although a pair of compasses and an engineer's scale will answer every purpose. In "laying the line around a hill," the curve should be made to cut the contours only slightly less rapidly than does the tangent, and in this respect especially does the detail map offer facilities for accurate adjustment that the field study does not afford.

After the paper location has been determined and the curves all drawn in, a profile should be made with an estimate of quantities and a disposition of the materials studied.

The paper location can be reproduced on the ground with sufficient accuracy by scaling the station plusses and distances to the right or left of the preliminary line of intersections of tangents and by locating these points by corresponding measurements in the field. To attempt to calculate the station number of the P. C. and P. T. of curves, or any other marked refinement appears to be scarcely worth while in view of the minor changes that may be made to advantage in the field, although some engineers attempt such refinements.

Selection of Curves. As suggested in the preceding paragraph, the proper degree of curve required to fit the topography can best be selected by laying forms cut to scale on the projected location on the detail map. Most curve forms are cut to a scale of 100 ft. to 1 in. and if the map is drawn to a scale other than this, the curve form must be selected accordingly, the degree varying inversely with the scale. Curves of various radii or degree can be drawn on tracing linen to the scale of the map and placed over the map instead of using the curve forms. Such curves on tracing linen can be stationed, and in this respect they offer an advantage over the ordinary rubber curves.

The curve should be selected so as to fit the ground most accurately. Curves less than 400 ft. long should not be used, and flat and reverse curves should be avoided if possible. Usually curves of even degree or even half degree can be found that will fit the topography and the convenience in making the calculation thereby promoted.

In running curves on location surveys, there is a diversity of practice as to the error allowable in the chaining and the instrumental work. Over the rough ground that is commonly encountered, great accuracy is not to be expected and is not essential. Some engineers are content if the last station of the curve is not in error more than 0.1 ft. per station of curve either in line or in distance from the P. T. as measured from the P. I. along the tangent, but it has been the author's experience that this is needlessly liberal, and that 0.05 ft. per station can be readily attained with a little care. It may be stated in passing that the errors are usually the fault of chaining rather than of measuring the angles.

In the following outline of the various curves used in railroad location and construction, no attempt is made to give in a complete manner the formulas necessary to the solution of the various problems that may arise, nor the derivation of such as are listed, but an attempt is made merely to explain the nature of such curves and their general use, employing a few formulas to illustrate their nature only, and leaving the full explanation of the same to the various field manuals that are available.

Simple Curves. Three different definitions of the degree of curve may be found in various writings, viz.:

1. *Long Chord Definition.* The degree of curve is the angle at the center subtended by a chord of 100 ft.

2. *Short Chord Definition.* The degree of curve is the angle at the center subtended by a chord of 100 ft., for all curves between 0° and 7°, by two 50-ft. chords for curves between 7° and 14°, by four 25-ft. chords for curves from 14° to 24°, and by ten 10-ft. chords for curves above 24°.

3. *Arc Definition.* The degree of curve is the angle at the center subtended by an arc of 100 ft.

The arc definition makes degree and radius readily convertible one to the other by the relation, $D = \frac{5730}{R}$, and this formula is commonly used for approximate calculations for the other definitions as well. The arc definition is the theoretically accurate one, but since practical methods of measuring by means of tapes do not permit the ready measurement of arcs, the next best is the short chord definition, which combines sufficient accuracy with practicability.

Simple curves are circular arcs and their use involves no other mathematical calculations than the geometry of the circle. For a complete exposition of railroad curves, the reader is referred to any one of the several field manuals on the subject. Fig. 83 shows the essential relationships. With the intersection point V located and the intersection (central) angle I measured, the first step is to locate the point of beginning of the curve, PC. $VB = VA = T = R \tan \frac{I}{2}$, and since the degree of curve

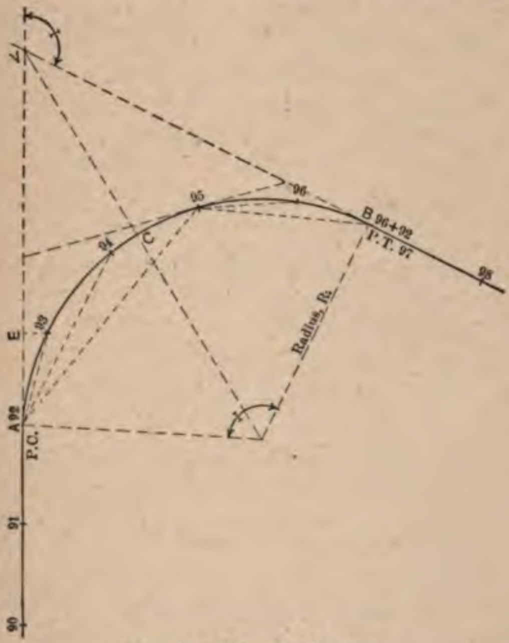

Fig. 83.—Simple Curves.

varies approximately inversely as the radius, the tangent distance, T, equals the tangent distance for a 1° curve divided by the degree of curve to be used. Tangent lengths and other functions of a 1° curve for various central angles can be found tabulated in various field manuals. With the transit at A, deflections for the successive stations are turned from the tangent and distances measured from A around the curve. The deflection angle to any point is obviously $\frac{DL}{2}$, D being the degree of curve and L the length in 100-ft. stations of the curve to the point. The final total deflection to the P. T. should be, of course, equal to one-half the total deflection or central angle. Since the curve is a circular arc, the same law of deflections applies at any point on the curve. Approximately, the external distance, the long chord, as well as the tangent distance, are proportional to the degree of curve, so that with these functions tabulated for a 1° curve they may be readily calculated for any degree by simple division. The tangent offset, equal to $\frac{7}{8}L^2D$, may be used for laying out short curves without the aid of a transit. The mid-ordinate $\frac{C^2}{8R}$, and the ordinate at any point, $\frac{mn}{2R}$ (C being

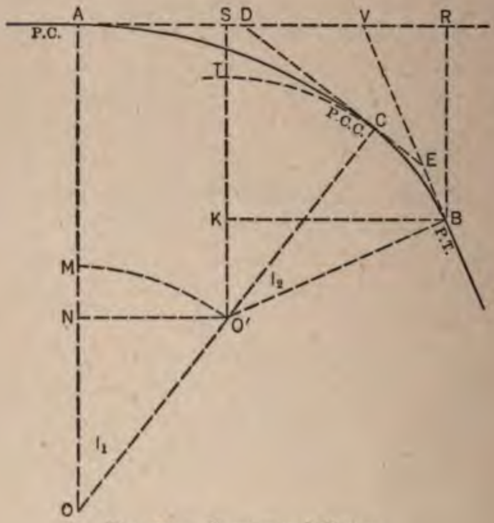

Fig. 84.—Compound Curve.

the length of chord, and m and n the segments to the foot of the ordinate, respectively), are quantities frequently used.

Compound Curves. Compound curves consist of two or more simple circular arcs joined together and having a common tangent at the point of compounding, and are employed to make the curve fit the topography more closely than can be done with simple curves alone. Fig. 84 shows the essential relationships of the two branches of a compound curve. The following or similar formulas for calculating the elements of compound curves are proved in most field manuals and are merely stated here:

D_1 and D_2 = degree of flatter and sharper curve respectively.
R_1 and R_2 = radii of flatter and sharper curve respectively.
I_1 and I_2 = central angles flatter and sharper curve respectively.
T_1 and T_2 = the longer and shorter tangent lengths respectively.
I = the total intersection angle.

$$I=I_1+I_2, \qquad (1)$$

$$I_1=2\tan^{-1}\left[\frac{T_2\sin I-R_2\operatorname{vers} I}{T_1+T_2\cos I-R_2\sin I}\right], \qquad (2)$$

$$I_2=2\tan^{-1}\left[\frac{R_1\operatorname{vers} I-T_1\sin I}{R_1\sin I-T_1\cos I-T_2}\right], \qquad (3)$$

$$T_1=(R_1-R_2)\sin I_1+R_2\sin I-T_2\cos I, \qquad (4)$$

$$T_2=-(R_1-R_2)\sin I_2+R_1\sin I-T_1\cos I, \qquad (5)$$

$$R_1=R_2+\frac{T_1+T_2\cos I-R_2\sin I}{\sin I_1}, \qquad (6)$$

$$R_2=R_1-\frac{R_1\sin I-T_1\cos I-T_2}{\sin I_2}. \qquad (7)$$

In the above equations, the maximum value of I_2 or I_1, is I and the maximum value of R_2 is $T_2\cos\frac{1}{2}I$.

Many of the problems arising in connection with compound curves can be conveniently solved graphically as shown in Fig. 85.* The perpendiculars erected at B and A meet at X. On

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* Field Engineering, W. H. Searles, p. 103.

VX describe a circle; this circle will obviously pass through *A*, *B*, *X*, and *V*. The bisector of the angle *AVB* cuts the circle at *C*.

Proposition I. The arc *APDB*, drawn with *C* as a center and *CA* as a radius, is the locus of all points of compound curvature.

$$\begin{array}{lrl} \text{Proof:} & \text{Ang. } CPO' = & \text{Ang. } CAO' \\ & CPO = & CBO \\ & CBO = & CAO' \\ & \therefore\ CPO = & CPO' \end{array}$$

and *O′P* and *OP* coincide forming the common radius. A point on *CP* at greater or less distance than the radius of the arc would not make the angle *CPO′* equal to *CAO′*, hence could not be a point of compound curve.

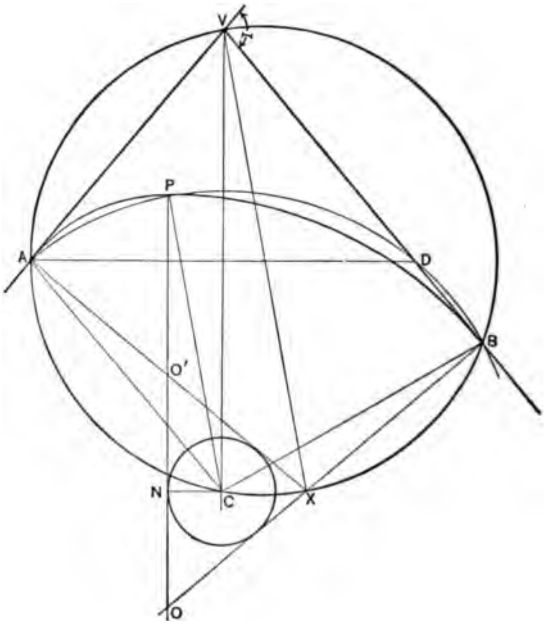

Fig. 85.—Graphical Solution of Compound Curves.

Proposition II. The circle with *C* as a center and a diameter equal to the difference between the tangent lengths is tangent to the radii of the curve drawn at the P. C., the P. C. C., and P. T.

Proof: Draw the perpendicular from C to the radius at N. Whatever the position of P (so long as it is on the arc), the size of the right-angled triangle, NPC, is constant, since the angle at P is constant, being always equal to CAX, and one side, CP, is constant, being the radius. Hence, the line NC is constant and the line PN is tangent to the circle.

These two propositions enable one to make a graphical plot on a contoured map and to select the elements of the compound curve that best fits the topography.

Reverse Curves. Reverse curves consist of two simple curves joined without an intervening tangent and curving in opposite directions. For main line construction, their use is to be condemned owing to the abrupt change in direction and superelevation. All curves on main line in reverse direction should have sufficient tangent intervening to allow cars to right themselves after leaving one curve before entering the next. The Committee of the American Railway Engineering Association recommend sufficient space between the points of spiral to allow at least four freight cars to right themselves before entering the second curve and 1000 ft. between the curves if such distance can be obtained without too great expense. On railroad location in mountainous regions, it is frequently difficult to avoid reverse curves, and as a result, in such regions, their use is common. The spirals at the adjacent ends of two curves in opposite directions may be shortened somewhat in order to provide a short piece of tangent between the curves, rather than to reverse at the point of spiral.

Transition Spiral. To avoid the sudden change from straight track to circular curve, transition curves are introduced which allow a train to enter a curve and to attain the superelevation of the curve gradually. A transition curve is one whose degree of curve varies with the distance from the beginning from 0 degree on the tangent to the degree of the circular curve where it joins the latter. This transition curve, as developed by Prof. A. N. Talbot * and adopted in a slightly modified form by the American Railway Engineering Association, can be run in with about the same facility as simple curves and in a similar manner. Without attempting to derive the equations for the use of this elegant spiral, the following elementary properties may be briefly stated which describe its essential features. See Fig. 86.

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* The Railway Transition Spiral, A. N. Talbot.

D is the degree of curve at any point on the spiral, a is the rate of change in degree per 100 ft., L the length of the spiral up to any point in 100-ft. stations. $D = aL$; the deflection angle from the point of spiral (P. S.) to any point, $\theta = \frac{1}{6}aL^2$; the total deflection angle, $\Delta = \frac{1}{2}aL^2$.

For moving up on the spiral, use is made of the property of the spiral that the rate of deflection from the osculating circle is constant and equal to $\frac{1}{6}aL^2$. Hence, to calculate the deflection at any point A to another point B, the deflection of the simple curve whose degree is that of the spiral at A is found for the chord AB, and the constant deflection of the spiral for the length AB is added or subtracted according as the point B is forward or backward on the spiral from A. To turn to the tangent at A, backsight on P. S. and turn off $\Delta_A - \theta_A$, or usually

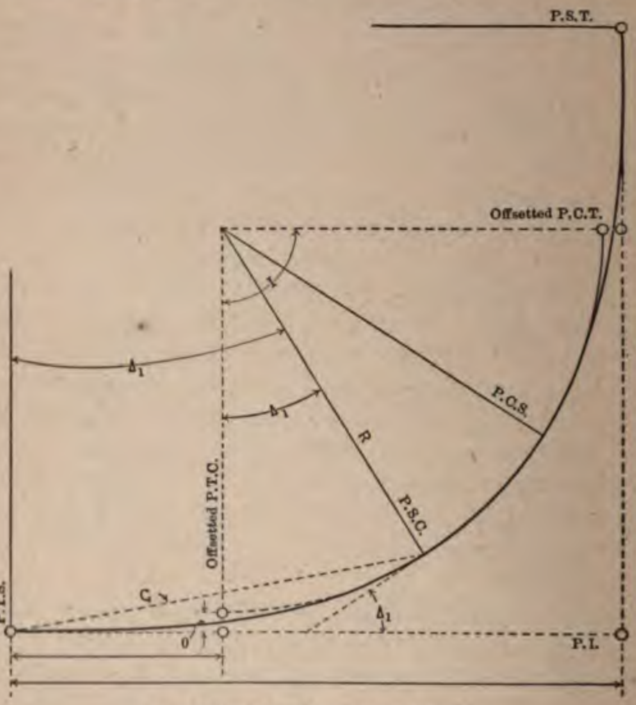


FIG. 86.—The Transition Spiral.

$2\theta_A$. The use of the spiral necessitates offsetting the simple curve inward from the tangent a certain distance, $o = .0727aL_1^3$, where L_1 is the total length of the spiral in stations. The total tangent length from the point of intersection to the P. S., where the spirals at both ends are similar, is,

$$T = 50L_1 - .000127a^2L_1^5 + (R+o)\tan\tfrac{1}{2}I.$$

The proper length of the spiral to use depends upon the rapidity with which a coach can be tilted for superelevation without discomfort to passengers and undue shock. If the superelevation is established according to the degree of curve, then the superelevation run-off is an inclined plane for the transition spiral. This rate has been found by experience to be about $1\frac{1}{2}$ to 2 ins. per second. The latter figure is used by the Chicago, Milwaukee and St. Paul Ry. and others with apparently satisfactory results, hence, it is adopted in this discussion.

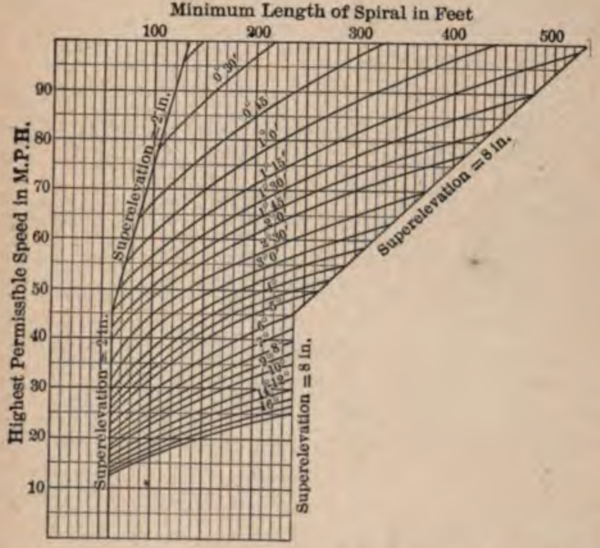


Fig. 87.—Minimum Length of the Transition Spiral.

The time required to attain the total superelevation, e inches, at this velocity is $\frac{e}{2}$ seconds. This superelevation, by a previous paragraph, is $.00066V^2D$ ins. Hence, where s is the length of the spiral in feet,

$$\frac{2s}{1.467V}=.00066V^2D, \quad \text{or} \quad s=.00050V^3D.$$

This equation indicates the proper length of spiral for a 2-in. rise per second. Spirals with 1½-ins. rise per second give easier riding curves, but the resulting spirals are one-third longer than the above would indicate. Fig. 87 gives the minimum length of spiral recommended by the American Railway Engineering Association, which represents lengths essentially the same as result from the above equation.

The present discussion does not warrant a more complete statement of the properties of this useful curve, and for its further applications the reader is referred to "The Railway Transition Spiral," by Prof. A. N. Talbot.

Vertical Curves. Wherever a break or change in grade occurs amounting to more than about 0.2 per cent algebraically, a vertical curve should be used to join the two grades. The difficulty in operating trains over a break in grade arises from the tendency of the rear cars to crowd or bunch on to those in front in passing over a sag, with a consequent sudden reversal in stress in the draft gear. Unless the break in grades is particularly sharp, no special danger arises in passing a summit, except that the strain in the draft gear is suddenly increased due to the fact that a part of the train at the instant of passing the summit ceases to be load and by virtue of gravity becomes a pulling force. Since the draft gear is designed to withstand a greater accelerating force than any reasonable difference in grade would cause, this difficulty is not serious. The rate of change in grade, therefore, might properly be made much greater over summits than through sags.

An entirely theoretical basis for choosing the proper rate of change of grade, or, in other words, the length of the vertical curve, is practically impossible, and most rules are formulated entirely from practice. The parabola has become almost universally used for vertical curves owing to the ease of calculating offsets to it. If 4 lbs. per ton be assumed as a minimum value of train resistance while running, then cars should not bunch in

1800.3

passing a sag where the difference in grades is not greater than 0.2 per cent. With the rate of change in grade of 0.2 per cent per station, this would make the length of the vertical curve in a sag $5(G_1-G_2)$, where G_1 and G_2 are the per cents of grades. However, the American Railway Engineering Association, from a study of practice of various roads, recommends longer curves than this would indicate. "The length should be determined by the gradients to be connected. On Class A roads, rates of change of 0.1 per station on summits and 0.05 per station in sags should not be exceeded. On minor roads, 0.2 on summits and 0.1 in sags may be used." This would make the length (in stations) of the curves as follows:

	Class A.	Minor.
On summits...........	$10(G_1-G\ )$	$5(G_1-G_2)$
In sags...............	$20(G_1-G_2)$	$10(G_1-G_2)$

These lengths would be difficult to obtain under most conditions of heavy grades.

Since the rate of change of gradient constitutes the second derivative of the elevation with respect to the length, the gradient being the first derivative, the curve thus formed is a parabola. The equation of this parabola may be derived as follows, L being the length along the curve in stations, and h, the elevation, of any point on the curve:

$$\frac{d^2h}{dL^2}=r, \text{ the rate of change;}$$

$$\frac{dh}{dL}=rL+C, \text{ when } L=0,\ \frac{dh}{dL}=\text{the grade } g;$$

$$h=\frac{rL^2}{2}+gL+C', \text{ when } L=0,\ h=\text{elevation of the first station, } E.$$

Hence,

$$h=\frac{rL^2}{2}+gL+E.$$

This equation can be used as a formula for finding the elevation of any point on the curve, or the elevations may be computed directly as follows:

Take a sag formed by a −0.5 and a +0.3 per cent grade on a class *B* road, the change in grade occurring at Sta. 870. The length of the vertical curve for a 0.1 rate of change would be 800 ft., or 400 ft. on either side of the vertex. Fig. 88. The deviation in rate of grade for the first station is half the allowed change, since the divergence is from a tangent to a chord instead of between two chords. The results may be tabulated:

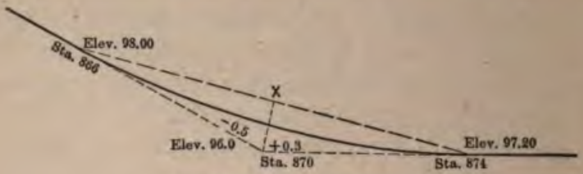


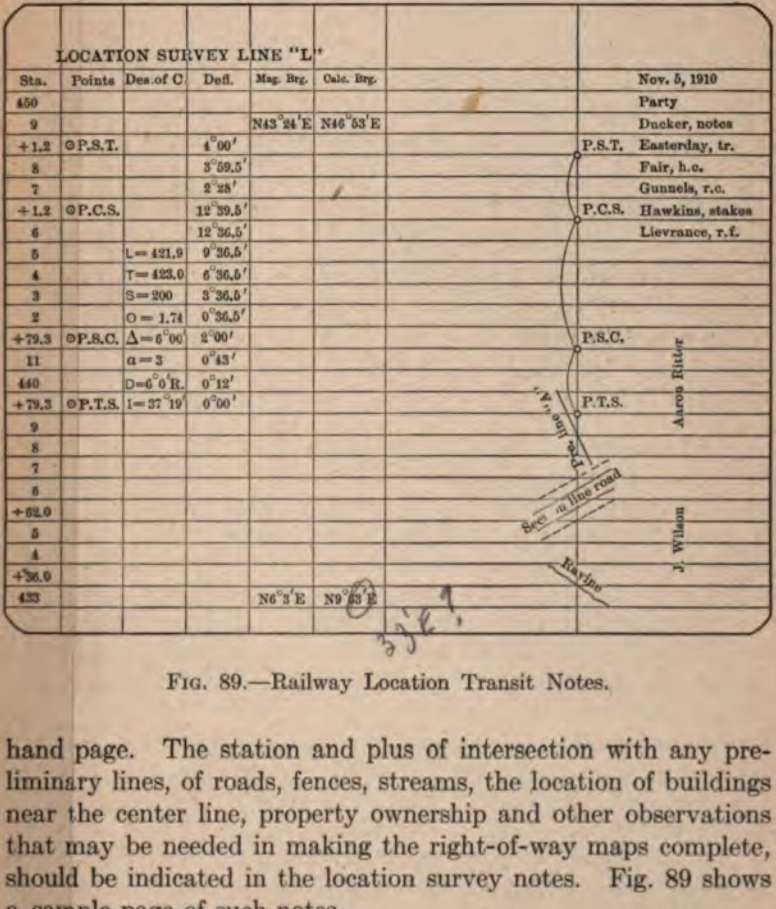
FIG 88.—Vertical Curve.

Elevation Sta. 866 = 98.0
867 = 98.0 − (0.5 − 0.05) = 97.55
868 = 97.55 − (0.45 − 0.1) = 97.20
869 = 97.20 − (0.35 − 0.1) = 96.95
970 = 96.95 − (0.25 − 0.1) = 96.80
971 = 96.80 − (0.15 − 0.1) = 96.75
972 = 96.75 − (0.05 − 0.1) = 96.80
973 = 96.80 − (−0.05 − 0.1) = 96.95
974 = 96.95 − (−0.15 − 0.1) = 97.20

870
871
872
873
874

Another method of calculating the elevations of stations on the vertical curve may be more convenient for short curves. The elevations of Stations 866 and 874 in the above problem are known from the original gradients when the length of the curve is known. These are 98.0 and 97.20 respectively. The elevation of *X* on the chord at the middle is the mean of these elevations, or 97.6. The middle point of the curve is half way between *X* and the vertex whose elevation is 96.00, hence the elevation of the middle of the curve is 96.80. By the property of the parabola that the ordinates vary as the square of the distance along the tangent, the offset at Station 867 is $\frac{1}{16}$ of .80 = 0.05. This added to the elevation of Station 867 on the straight grade gives 97.50 + 0.05 = 97.55. The ordinate at the second station, viz., Station 868, is four times 0.05, or 0.20. This added to 97.00, the elevation on the regular grade gives 97.20, the elevation on the curve. The remainder of the elevations can be calculated in a similar manner.

Notes. Location survey notes are kept in an ordinary transit note book in a similar manner to preliminary survey notes. On the left-hand page are shown all alignment notes including curve description and curve deflections, spiral deflections, etc. Sketches and supplementary notes are recorded on the right-hand page. The station and plus of intersection with any preliminary lines, of roads, fences, streams, the location of buildings near the center line, property ownership and other observations that may be needed in making the right-of-way maps complete, should be indicated in the location survey notes. Fig. 89 shows a sample page of such notes.



LOCATION SURVEY LINE "L"

Sta.	Points	Des. of C.	Defl.	Mag. Brg.	Calc. Brg.		
							Nov. 5, 1910
450							Party
9				N43°24'E	N46°53'E		Ducker, notes
+1.2	⊙P.S.T.		4°00'			P.S.T.	Easterday, tr.
8			3°59.5'				Fair, h.c.
7			2°28'				Gunnels, r.c.
+1.2	⊙P.C.S.		12°39.5'			P.C.S.	Hawkins, stakes
6			12°36.5'				Lievrance, r.f.
5		L=421.9	9°36.5'				
4		T=423.0	6°36.5'				
3		S=200	3°36.5'				
2		O=1.74	0°36.5'				
+79.3	⊙P.S.C.	Δ=6°00'	2°00'			P.S.C.	
11		a=3	0°43'				
440		D=6°0'R.	0°12'				
+79.3	⊙P.T.S.	I=37°19'	0°00'			P.T.S.	
9							
8							
7							
6							
+62.0							
5							
4							
+36.0							
433				N6°3'E	N9°53'E		

Pre. line "N"
Sec'n line road
Ravine
Aaron Ritter
J. Wilson

FIG. 89.—Railway Location Transit Notes.

Location Profile. Careful levels are run over the located line and a profile plotted similar to that of the preliminary, and the projected grade lines are drawn. It is rarely necessary to use gradients with greater refinement than the nearest tenth per cent. Compensation may well begin at the nearest even station to the P. C. of the simple curve, or the middle of the spiral, or where a vertical curve is desirable because of the compensation, the vertical curve may be extended along the spiral. Vertical curves should be drawn on the profile and all compensations allowed for and indicated. The location profile should show all information needed in carrying on construction, such as high-water marks, soundings, estimated quantities, positions and types of bridges, etc.

On the same sheet at the bottom should be shown the alignment as illustrated in Fig. 90. While other conventions have been used for showing the alignment, this is the one adopted by the American Railway Engineering Association, and it has the advantage of representing to scale the horizontal projection of the profile, and points on the one correspond exactly to corresponding points on the other, a relation that does not obtain when arbitrary curves are used to illustrate curved alignment.

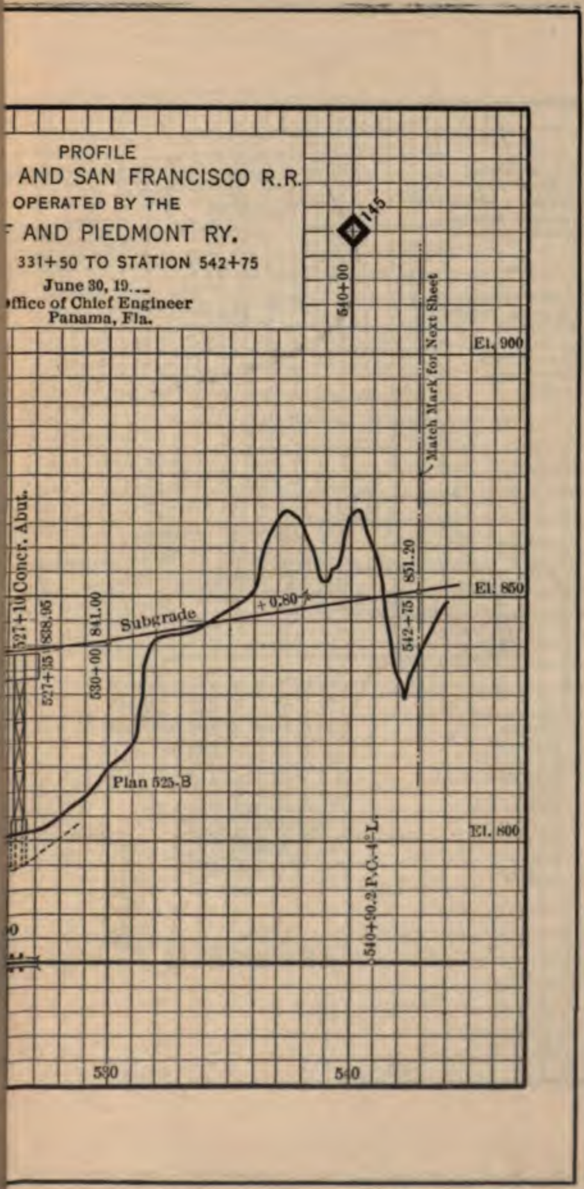
A complete profile that well illustrates good practice is required to be furnished by the Interstate Commerce Commission, as shown in Fig. 90, which will be made up thus:

"(*a*) *Roadway.*—Show: The vertical projection of the original ground surface on center line of the railway; present grade line (top of roadbed subgrade); rates of grade, elevations (sea level datum) at all points of change of grade at each end of sheet and where profile is broken; and station and plus to points of change of grade, and the station numbers at each 1000-foot interval near the lower border of the sheet.

"(*b*) *Structures.*—Show: Bridges, trestles, culverts, retaining walls, tunnels and other roadbed structures in vertical projection, stating kind and general dimensions, average depth of penetration of piling in each bent in trestles or other under-structures, by vertical projection; character of and depth of foundation bed of masonry structures by vertical projection; reference to railway file numbers of detail standard or special plans by which the structure was built; existing mile posts; and the station and plus of each of the above indicated improvements.

"(*c*) *Quantities.*—Give a summary of construction quantities to subgrade, including roadway, bridges and culverts.

"(*d*) *Alignment and Track.*—Show in the lower $2\frac{1}{2}$-in. space of the profile sheet the center line of each main track developed into straight line or lines, with alignment notes of curves stated in figures; the station



(*To face page 438*)

and plus at points of curves and tangents, and other data, such as passing tracks, depot buildings, water and fuel stations, highway crossings, and important water courses that will assist in interpreting the profile. For plotting transversely, a scale of 1 in. equals 200 ft. shall be used."

Right of-way Maps. For permanent records, right-of-way maps should be made to a uniform scale and size of sheet showing width and other features of the right of way (R.O.W.), the owners of contiguous property, as well as the dimensions and descriptions of the various parcels owned by the railroad. Fig. 91 shows the form of right-of-way map prescribed by the Interstate Commerce Commission, which is a very complete illustration of this class of maps. Maps of city right of way are necessarily drawn to a larger scale and show property rights in more detail. For convenient reference, maps of station grounds are frequently drawn as sketches and not to scale, the important features being shown enlarged. The Interstate Commerce Commission has issued the following instructions concerning the preparation of right-of-way maps:

"On the Right-of-Way and Track Map shall be shown the following data:

"(*a*) *Boundary Lines of All Right of Way.* The term right of way as herein used includes all land owned or used for purposes of a common carrier, no matter how acquired.

"Show: Width of right of-way, in figures, at each end of the sheet and at points where a change of width occurs, with station and plus of such points; boundary lines and dimensions of each separate tract acquired; a schedule of deed, custodian's number, the name of grantor and grantee, kind of instrument, date and book and page where recorded. Each tract of land shall be given a serial number and listed serially in the schedule. The schedule shall also include reference to leases to the company, franchises, ordinances, grants, and all other methods of acquisition.

"(*b*) *Boundary Lines of Detached Lands.* Where same can be shown clearly. The term detached lands as herein used includes:

"(1) Lands owned or used for purposes of a common carrier, but not adjoining or connecting with other lands of the carrier.

"(2) Lands owned and not used for purposes of a common carrier, either adjoining or disconnected from other property owned by the carrier.

"Show: Boundary lines and dimensions; distance and bearing from some point on the boundary line to some established point or permanent land corner, where practicable, and separately, on the schedule above, the lands not used for purposes of a common carrier.

" (c) *Intersecting Property Lines of Adjacent Landowners.* Where the information is in the possession of the carrier show: The property lines of adjacent landowners, the station and plus of important intersections of property lines with center line of railway or other railway base line, and the names of owners of the land adjacent to the right of way.

(d) *Intersecting Divisional Land Lines.* Show: Section, township, county, State, city, town, village, or other governmental lines, with names or designations; the width and names of streets and highways which intersect the right of way; and the station and plus at all such points of crossing or intersections with center line of railway or other railway base line.

" (e) *Division and Subdivision of Lands Beyond the Limits of the Right of Way.* Where the information is in the possession of carrier show: The section and quarter-section lines for a maximum distance of 1 mile on each side of the center or base line of railway where the land has been subdivided into townships and sections; such data as to divisions, tracts, streets, alleys, blocks, and lots, where the land has been divided in some other way than by sections; the distance, where known, from railway base line to permanent land corners or monuments; and the base line from which the railway's lands were located (center line of first, second, third, or fourth main track or other base line).

" (f) *Alignment and Tracks.* Show: The center line of each main and side track when such tracks are outside the limits covered by the Station Maps and center line of each main track, also inside Station-Map limits; the length, in figures, of all sidetracks from point of switch to point of switch, or point of switch to end of track; all other railways, crossed or connecting, and state if crossing is over or under grade, and give name of owner of such tracks; survey station number at even 1000 scale-feet intervals, and station and plus at points of all main line switches at points of curves and tangents and at beginning and ending points on each sheet; the degree and central angle of curves; and joint tracks and ownership thereof.

" (g) *Improvements.* Show: Station and office buildings, shops, enginehouses, fuel stations, water stations, etc. (owned by the carrier), in general outline, where it can be done clearly. Also indicate conventionally: Bridges, trestles, culverts, tunnels, retaining walls, cattle guards, mileposts, signal bridges and ground masts, fences by note only, and other principal railway structures owned by the carrier, with general data as to dimensions; and, where practicable, pipe lines, sewers, underground conduits, paving, curbing, or similar works located on the right of way of the carrier or adjoining and owned by the carrier in whole or in part. Give station and plus to all important structures which are outlined above.

"(*h*) *Topographical Features.* Show: Rivers, creeks, water courses, highway crossings, etc. Give names, where known, and when highway crossings are over or under grade, so state."

Description of Right of Way. Describing accurately an irregular piece of land is not a simple process. Where the parcel consists of a strip of uniform width, the description frequently refers to it as a strip —— feet wide, —— feet on either side of the X & Y railway, and containing —— acres, more or less. This description would be improved if in addition to the above statement the complete referencing as to township and range lines were included. In the eastern states, the rectangular system of public land surveys does not obtain, hence description by metes and bounds is the only recourse there, and, indeed, this may be the best method in other cases as well. Where the boundary of the tract involves curves, it is necessary to describe the courses in terms of such curves, preferably avoiding spiral curves in the description, for they lack definiteness, and ordinary curves of circular arcs will suffice.

A very common form of description is as follows: All that tract or parcel of land situated in the County of —— and State of ——, and consisting of a strip of land —— feet wide, —— feet on either side of the located center line of the X & Y Railroad where the said railroad passes through the lands of the party of the first part; the said located center line being described as follows, to-wit: Beginning with the intersection of the said located center line of the X & Y Railroad with the westerly boundary line of Section 4, Township 63 N., Range 8 W. of the 4th Principal Meridian, distance southerly on said section line 1762.4 ft. from the W.N. corner of Section 4, and running thence N 46° 12′ E, true bearing, 2260.0 ft., more or less, to the intersection of the said located center line of said railroad with the northerly boundary line of said Section 4; containing —— acres, more or less.

Tunnel Surveys. Tunnels may be built through hills too high or too steep to surmount and under streams too wide to bridge. When a hill or ridge is so low that a transit line and levels can be run directly over the top, the surveys for tunnel construction are very simple, but where triangulation must be resorted to the necessity for extreme accuracy in the operations

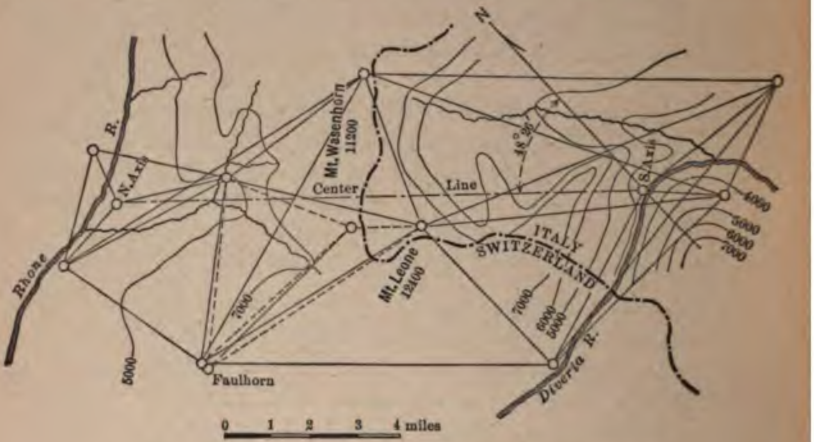


FIG. 92.—Triangulation for the Simplon Tunnel.

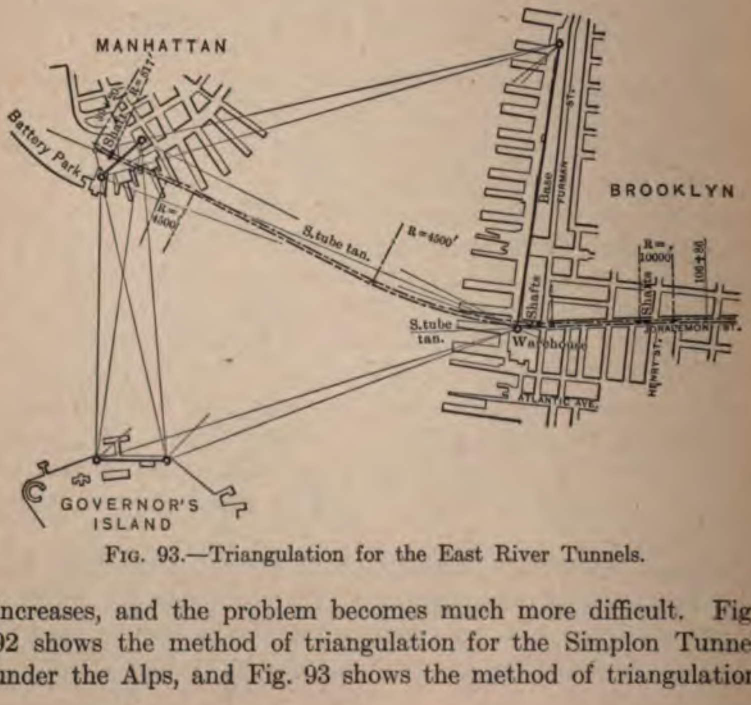


FIG. 93.—Triangulation for the East River Tunnels.

increases, and the problem becomes much more difficult. Fig. 92 shows the method of triangulation for the Simplon Tunnel under the Alps, and Fig. 93 shows the method of triangulation employed in establishing line for the tunnel under East River between New York and Brooklyn.*

In the former case, astronomical instruments of great precision were employed, while in the latter ordinary engineering transits were used. The former tunnel is 9.25 miles long and the latter 1.14 miles long. The results with respect to accuracy of some tunnel surveys are given below:

TABLE LVII

ACCURACY OF TUNNEL SURVEYS

Tunnel.	Date Opened.	Length, Miles.	Error.		
			Line, Ft.	Elevation, Ft.	Length, Ft.
Mt. Cenis............	1871	7.9	0	1.0	45 too long
St. Gothard...........	1881	9.25	1.08	0.16	25 too short
Simplon..............	1905	11.0	0	0.33	6.4
Manhattan Ry........	1902	1.0	0.16	0	
E. River, So..........	1907	1.14	0.01	......	0.2
E. River, No..........	1908	1.14	0.13	0.01	0.2

Line and elevation determination are by no means the most difficult and indefinite part of tunnel surveys. A study of the geological formations by observation of outcroppings and by borings is essential in order to predict the character of the material to be penetrated. Where the outcrops indicate hard rock without much weathering, it is probable that solid rock will be encountered, but where the outcrops are seamy and fissured, it is altogether likely that timbering will be necessary. Strata of clay and sand should especially be looked for.

Cost of Surveys. The railroads that were located during the last century were located at a cost of probably less than $100 per mile on the average. In fact, a statement frequently met with is that preliminary and location surveys for a railroad average $100 per mile and vary from $50 to $150 per mile. As a matter of fact, with the increased wages and superior type of engineers on railroad work at the present day, perhaps the average cost should be considered as being between $150 and $200, and it will frequently amount to $400 or $500 per mile. Where a careful study of economic conditions is made, the cost will very naturally be higher than where the line is projected following the topography generally and accepting whatever grades may be readily secured. The following data, Tables LVIII and LIX*, give an idea of relative costs and rates of progress on preliminary and location surveys. The length of line in question was 179 miles as located, representing conditions of rough broken country rather than easy. The work was distributed among four parties and was done in 1902. The average cost of preliminary surveys of a total of 563 miles was $25.98 and of locating 179 miles was $70.38 per mile. The total cost of reconnaissance, preliminary lines and extra office work was $192.30 per mile, on the 179-mile basis.

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* Trans. Am. Soc. C. E., Vol. LXXV, p. 68.

The cost of locating the Chicago, Milwaukee and St. Paul Ry. in the woods of Wisconsin was $142.80 per mile.

Table LX† gives the cost of surveys of a number of railroads in West Virginia and includes the total charge against engineering from the inception of the project to the beginning of construction, a portion of which covered the cost of instruments.

TABLE LVIII

COST OF PRELIMINARY RAILROAD SURVEYS

Item.	Party No. 1.	Party. No. 2.	Party No. 3.	Party No. 4.
Days worked	87	90	111	30
Miles run with topography taken	145.8	166.3	164.1	23.2
Miles run without topography taken	39.3	......	16.0	3.6
Total miles preliminary run	185.1	166.3	180.1	26.8
Average daily number of men	16	15	18	21
Average miles per day per party	2.12	1.85	1.62	1.06
Average daily cost subsistence per man	$0.37	$0.49	$0.38	$0.58
Average daily pay per man	1.81	2.03	1.66	1.66
Daily cost per team	6.00	6.22	6.92	12.87
Contingencies	88.48	112.96	91.84	125.73
Daily cost per man, total	2.63	3.03	2.49	3.05
Cost per mile	19.61	24.07	28.08	60.95
Character of country	heavy	light	average	average

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* "Railroad Location Surveys and Estimates," F. Lavis, p. 199.

† Railroad Surveys, W. S. McFetridge, Trans. Am. Soc. C. E., Vol. 65.

TABLE LIX

COST OF RAILROAD LOCATION SURVEYS

Item.	Party No. 1.	Party No. 2.	Party No. 3.	Parties 2 and 3 Combined.	Party No. 4.
Days worked.............	65.0	38	7.5	42.5	39
Average daily number of men	22	19	19	31	19
Average miles per day.....	0.86	1.02	0.95	0.89	0.65
Average daily pay per man.	$1.72	$1.61	$1.61	$1.71	$1.60
Average daily cost per man.	2.50	2.36	2.39	2.57	2.50
Contingencies.............	143.36	46.76	15.70	196.00	133.84
Cost per mile.............	62.57	44.33	47.50	90.47	81.72

TABLE LX

COST OF RAILROAD SURVEYS

Company.	Amount Spent.	Miles of Surveys.			Average Cost per Mile.	Average Cost per Mile of Location.
		Preliminary.	Location.	Total.		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
L. K. R. R.....	$25,076.83	428.19	193.85	622.04	$40.31	$129.36
Z. M. & P......	19,812.77	509.03	105.23	614.26	32.25	188.28
B. & E. R. R...	20,466.68	241.75	113.70	355.45	57.58	180.00
P. B. & T. R. R.	6,651.98	84.56	38.17	122.73	54.20	174.28
B. & N. R. R...	19,249.94	162.51	151.29	313.80	61.34	127.23
Totals.......	$91,258.20	1,426.04	602.24	2,028.28	$45.00	$151.53

CHAPTER XXV

CONSTRUCTION SURVEYS

Organization of Engineering Force. After the location survey has been completed, a large amount of surveying and other engineering work must be done in connection with the construction. The work of the locating engineer, as such, is, of course, completed, but he is usually retained in some capacity during construction, frequently as chief engineer. The most common organization for constructing a new line is to place the entire work in charge of a chief engineer, with division or district engineers and assistants, and to divide the entire length of line into residencies, usually 4 to 10 miles long, each of which is placed in charge of a *resident engineer*, who reports to a division engineer or to an assistant engineer. A resident engineer should have the training requisite for a good transitman, and in fact the office is most commonly filled by one who has served as transitman. He is usually assigned two assistants and is given a transit, level, and accessory equipment. His duties are to do all instrument work required along the line, such as setting slope, grade and line stakes, to inspect all construction on his residency, and to represent in general the chief engineer in his relation to the contractors, to whom the actual work of grading, driving piles, etc., is usually let. Sometimes the entire job on a long stretch of line is let to one large contractor who sublets portions of it to smaller contractors who may live along the line, or he may undertake to do all of the work with his own forces. In any case, the resident engineer is the representative of the engineering department of the railroad to whom the contractor and his foremen look for instructions. The resident engineer must see to it that all work is done according to the specifications, and must submit monthly estimates of work done to serve as a basis for the monthly payment to the contractor. The resident engineer should study the specifications diligently in order that he may know their significance, intent and true meaning in every detail and thereby be able to answer authoritatively any question that the contractor may raise concerning the same.

The complete equipment that should be furnished to the resident engineer is as follows:

One transit
Two range poles
Transit note book
One level
One level rod
Level note book
One 100-ft. steel tape
One 50-ft. metallic tape
One ax
Marking crayons (1 doz.)
Quantity of tacks
Quantity of drafting pencils
Pencil, ink and cleaning erasers
Penholders and pens
Colored pencils
Scratch pads
Stationery
Drafting ink, black, red and perhaps some other colors
Quantity of rubber bands
Small roll detail paper
Small roll profile paper
Small roll cross-section paper
Small roll tracing cloth

Setting Slope Stakes. Slope stakes are light stakes, usually about 1 in. by 2 ins. by 1 ft. long, that are driven at the toe of slopes of embankments and at the top of slopes in excavations, to direct the contractor in making the excavations and embankments. On the back of the stake, i.e., away from the center line, is indicated the center height as cut or fill, and on the front side, the side height, using "F" to indicate fill and "C" to indicate cut. Many engineers mark the center cut or fill on the back of the center line stakes that are already in place. As soon as grading is begun, however, these stakes are disturbed, hence the practice of placing the marks on the slope stakes is believed to be preferable. The slope stake is commonly slanted toward the center line at the top of cuts and away from the center line at the bottom of fills, in order to be more nearly at right angles to the surface that they limit.

Where the grade line passes from cut to fill (grade point), Fig. 94, slope stakes should be set at r, o and m, and cross-sections opr and mxn taken, in order that the pyramidal solids of which these sections are the bases may be computed.

The process of setting slope stakes is very simple in practice but rather difficult to make clear in a brief description. The correct position of the stake is found by a series of approximations, which may be best illustrated by an example. Assume a 24-ft. roadbed with side slopes of $1\frac{1}{2}$ to 1. With a center height of 6.4 ft., if the ground were level transversely, the slope stake would be set out $12+1.5\times6.4=21.6$ from the center line. If, however, the ground appears to rise from the center line outward, the instrumentman estimates the amount of rise somewhat farther out than 21.6 ft. Suppose he estimates the ground to be 1.5 ft. higher than at the center, then the stake should be set, according to assumption, $12+1.5(6.4+1.5)=23.9$ ft. out from the center line. He then directs the rodman to set the rod 23.9 ft. from the center line, and having previously set up his level with a backsight on the center line station, he ascertains the elevation of this point with reference to the center line station. If he finds that his estimate of 1.5 ft. was essentially correct, he directs the stake to be marked $C7.9$ and driven at this point. If, however, his reading on the rod indicates that the ground there is actually 2.0 ft. higher, he recalculates his distance out, $12+1.5(6.4+2.0)=24.6$ ft., and in a similar manner he tests this distance by reading the rod 24.6 ft. out. A similar

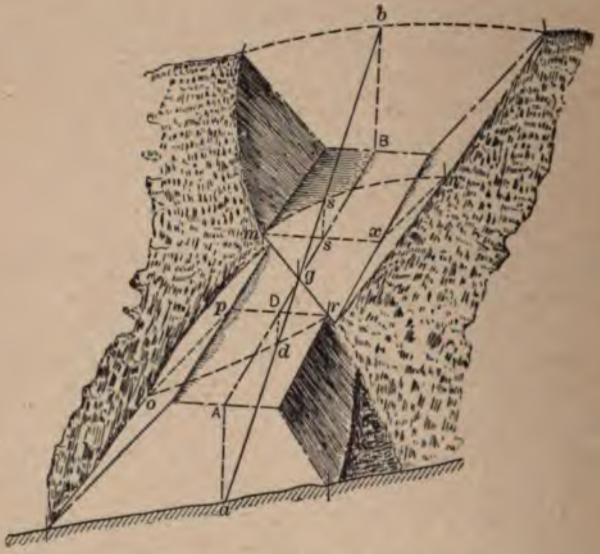

Fig. 94.—Roadway at a Grade Point.

procedure would be followed in the event that he had overestimated the rise, except that the rod would be brought toward the center line instead of away from it. With a little experience, an instrumentman should not need more than the second trial, and usually only the first, to set the stake within 0.1 ft. of the exact spot, and this is close enough. The position of the stake is recorded in the note book thus, $\frac{+8.4}{24.6}$, the number over the line

CROSS SECTIONS LINE "L"						Base Cuts 20 ft. Fills 16 ft. Slope 1½ to 1 1½ to 1		
STA.	SURF. EL.	GR. EL.	GRADE		CLASS'N	LEFT	CROSS SECTIONS	RIGHT
101	794.2	790.06			Com.	$\frac{+4.0}{16.0}$	+4.1	$\frac{+4.8}{17.2}$
100	793.0	789.06			"	$\frac{+3.6}{15.4}$	+3.9	$\frac{+4.2}{16.3}$
99	789.7	788.06			L. Rock	$\frac{+1.4}{12.1}$	+1.6	$\frac{+3.3}{14.9}$
+82	788.3	787.90	+1.0% from Sta. 80 to Sta. 132		"	$\frac{0.0}{10}$	+0.4	$\frac{2.4}{13.6}$
+74	787.8	787.82				$\frac{-0.8}{9.2}$	0.0	$\frac{+1.2}{11.8}$
+63	787.2	787.71				$\frac{-1.6}{10.4}$	-0.5	$\frac{+0.6}{10.9}$
98	786.1	787.06				$\frac{-2.4}{11.6}$	-1.0	$\frac{0.0}{10.0}$
+67	785.2	786.73				$\frac{-3.2}{12.8}$	-1.5	$\frac{-1.2}{9.8}$
+50	784.0	787.56				$\frac{-6.0}{17.0}$ $\frac{-4.2}{8.0}$	-3.6	$\frac{-3.8}{8.0}$ $\frac{-3.0}{12.5}$
97	783.6	786.06				$\frac{-3.6}{13.4}$	-2.4	$\frac{-1.6}{10.4}$
96	782.4	785.06				$\frac{-3.6}{13.4}$	-2.5	$\frac{-2.0}{11.0}$
95	781.6	784.06				$\frac{-3.4}{13.1}$	-2.5	$\frac{-2.0}{11.0}$

FIG. 95.—Cross-section Notes.

indicating the distance of the point above or below grade and the figure below the line the distance from the center to this point. In embankment, the minus sign is used to indicate the elevation. The notes are kept as shown in Fig. 95.

Where slips are likely to occur, the cross-section should be extended beyond the slope stake, and where a three-level section does not show all breaks in the transverse slope, additional heights should be read, as provided in the next paragraph.

Slope boards are frequently used in setting slope stakes. These consist of a long board (about 15 ft.) with a bubble on the upper edge and with graduations on the under edge. Special tapes graduated for different slopes are sometimes used also. The use of these is so simple that extended explanation is needless.

Taking Cross-sections. A cross-section shows a transverse profile of the ground surface for a short distance on either side of the line. It is a permanent record of the surface of the ground, provided the elevation of the center stake is known. By taking cross-sections before and after excavations or embankments are made, the area between the lines representing the surface of the ground in the two cases is the amount of earth removed or placed, as the case may be.

A cross-section is taken by referring the elevation at every break in grade to the elevation at the center stake, which is definitely known from the profile. The process is about as follows, with three men in the cross-sectioning party. The rodman gives the levelman a reading on the ground at the center stake, and then carrying the end of the tape and the rod, he gives readings at every break in transverse slope, while the third man, standing at the center with the tape in his hand, keeps the rodman at right angles to the line as the latter moves outward, and also reads the distance out to the rod at the points where readings are taken. The notes are recorded in a manner similar to that described above in connection with setting slope stakes, (+) representing a point above the center elevation and (−) a point below. Thus, $\frac{-6.2}{21.0}$ represents a point 6.2 ft. below the grade at the center and 21.0 ft. from the center. The notation is made on the right or left of the center line of the page according as the point is on the right or left of the surveyed center line. These notes for earthwork on a projected line are naturally taken in connection with the setting of the slope stakes, the recorded position of the latter forming a part of the cross-section. The method of calculating the earthwork volumes from such notes will be discussed in the next paragraph.

Special cross-section rods are on the market having an endless band from the bottom to the top of the rod which can be shifted and clamped in any position. When the levelman reads the rod at the center stake, the rodman shifts the band carrying the graduations until the levelman reads zero; then the reading at any other point will represent the distance of that point above or below the center elevation.

Sometimes on extensive excavations with very deep cuts, cross-sections can best be taken by reading the vertical angle with a transit and measuring the slope distance, the tops of slopes being very easily located in this manner.

Earthwork Calculations. From the cross-section notes as described in the preceding paragraphs, the amount of earthwork in excavation or in embankment can be readily computed. There are two steps involved, viz.:

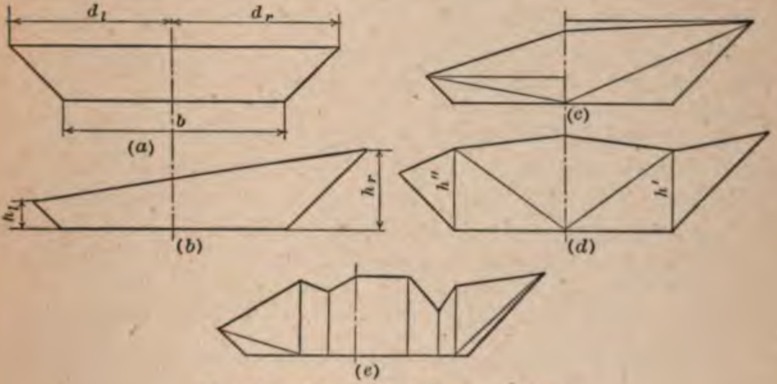

FIG. 96.—Earthwork Cross-sections.

a. Calculating the area of the cross-section.

b. Calculating the solidity from the cross-section areas.

The area of the cross-section can always be divided into triangles, trapezoids, etc., which will permit the area of the section to be computed. Five types of cross-sections may be mentioned:

1. A *Level Section* is shown in Fig. 96 (*a*) and its area is readily seen to be $c(b+sc)$.

2. A *two-level section* is shown in Fig. 96 (*b*) and its area may be shown to be $\left(\frac{b}{2}+d_r\right)\frac{h_l}{2}+\left(\frac{b}{2}+d_l\right)h_r/2.$

3. A *three-level section*, as shown in Fig. 96 (*c*), has an area equal to $\frac{c(d_l+d_r)}{2}+\frac{\frac{b}{2}(h_l+h_r)}{2}$.

4. The area of a *five-level section*, Fig. 96 (*d*) may be determined as $\frac{cb}{2}+\frac{h'd_r}{2}+\frac{h''d_l}{2}$.

5. *Irregular sections* must be divided into triangles and trapezoids of which the areas can be computed separately and totaled, Fig. 96 (*e*).

c = center height in feet;
d_l = distance out on the right;
d_r = distance out on the left;
s = side slope;
b = width of base;
h' and h'' = additional side heights.

In calculating the volume from the areas of the cross-sections, two methods are in use, the first being approximate and the second theoretically exact. The first consists in averaging the end areas and multiplying by the length between sections, and the second of calculating a mid-section and using the prismoidal formula, which is $Q=\frac{l}{6}(A_1+4A_m+A_2)$,* Q being the quantity of earthwork, l the distance between sections, A_1 and A_2 the areas of the end sections, and A_m the area of the mid-section.

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* For any prismoid, the end area may be considered as the product of two lines. Let b_1 and d_1 be these lines for one end and b_2 and d_2 the corresponding lines for the other end. The area of a section x distance from the one end will be

$$\left[b_2+(b_1-b_2)\frac{x}{l}\right]\left[d_2+(d_1-d_2)\frac{x}{l}\right],$$

and the volume of the prismoid

$$V=\int_0^l\left[b_2+(b_1-b_2)\frac{x}{l}\right]\left[d_2+(d_1-d_2)\frac{x}{l}\right]dx$$

$$=\frac{l}{6}\left[b_2d_2+(b_1d_1+b_2d_2+b_2d_1+b_1d_2)+b_1d_1\right].$$

The area of the mid-section

$$=\frac{b_1+b_2}{2}\times\frac{d_1+d_2}{2}=\frac{b_1d_1}{4}+\frac{b_1d_2}{4}+\frac{b_2d_1}{4}+\frac{b_2d_2}{4}.$$

$$\therefore V=\frac{l}{6}(A_1+4A_m+A_2).$$

This formula gives more nearly accurate results than does averaging end areas, but it is seldom used for the calculation of earthwork owing to the additional complexity and also to the fact that field measurements are not taken with great refinement, hence the computations need not be done with special precision. Sometimes the increased accuracy of this formula is obtained by applying a *prismoidal correction* to the results obtained by averaging end areas. For a more complete exposition of this method the reader is referred to a field manual, such as Allen's " Railroad Curves and Earthwork," p. 154 ff.

Where earthwork is calculated by averaging the end areas, diagrams and tables are frequently used to assist in the computations. For the typical cross-sections, the following formulas apply, giving the total solidity for a 100-ft. station with the cross-section indicated by the dimensions:

Level section: $Q=\frac{100}{54}(b+sc)2c;$

Two-level section: $Q=\frac{100}{54}\left[\left(\frac{b}{2}+d_r\right)h_l+\left(\frac{b}{2}+d_l\right)h_r\right];$

Three-level section: $Q=\frac{100}{54}\left[\frac{(d_l+d_r)}{2}c+\frac{b}{2}\left(\frac{h_l+h_r}{2}\right)\right];$

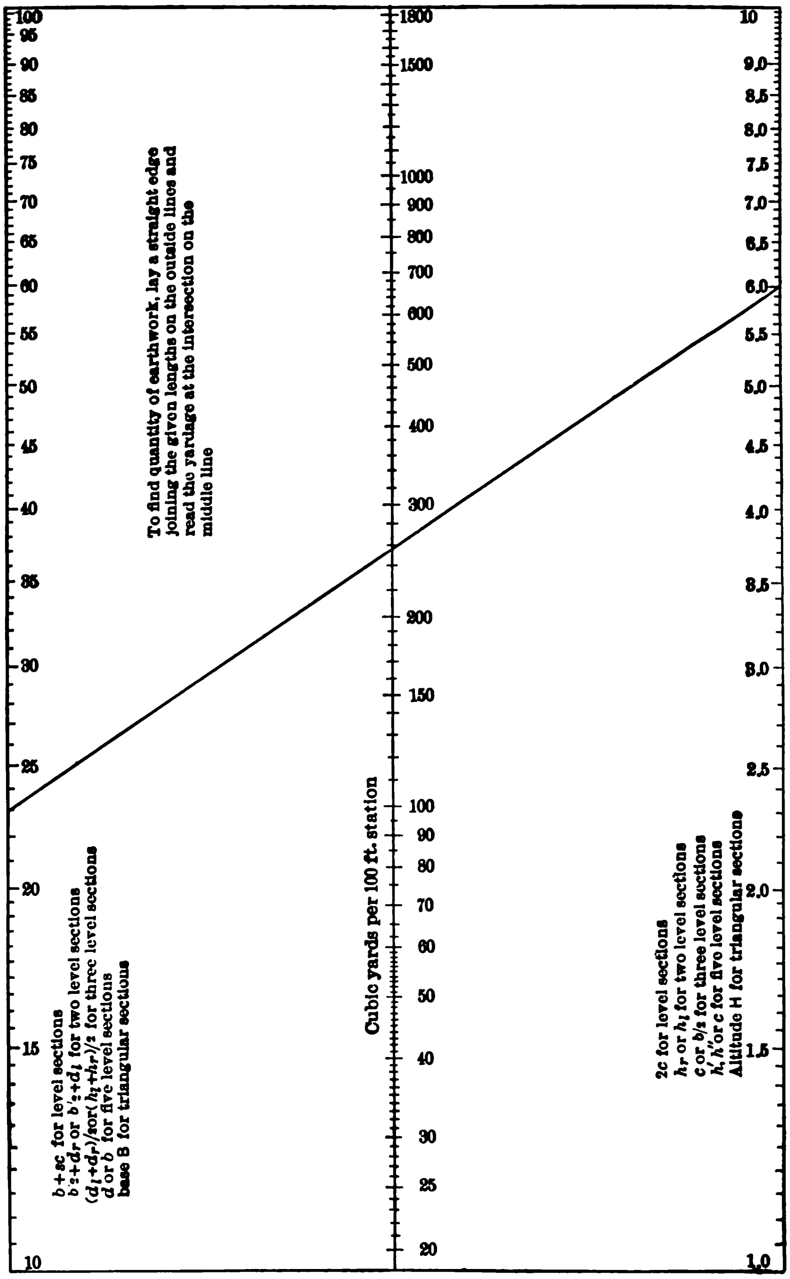
Five-level section: $Q=\frac{100}{54}[bc+h'_r d_r+h'_l d_l];$

Triangular prism: $Q=\frac{100}{54}\times B\times H;$

Pyramidal section: $Q=\frac{100}{54}\times B\times\frac{H}{3}.$

The diagram in Fig. 97 is a nomographic chart that enables the product of two numbers multiplied by $\frac{100}{54}$ to be readily obtained by laying a straightedge joining the two numbers on the two outside scales and reading the desired product on the middle scale. It will be observed that the above formulas consist of such a product or a sum of two or more such products, hence, by successively finding these products and adding the results, the total solidity for 100 ft. can readily be found.

For example, with a level section having a 20-ft. base, 1½



To find quantity of earthwork, lay a straight edge joining the given lengths on the outside lines and read the yardage at the intersection on the middle line

Fig. 97.—Graphical Calculation of Earthwork Quantities.

to 1 slopes, and a 3-ft. center height, the solidity is read from the center scale as 256 cu.yds.

The ready application of the diagram to the other cases is obvious. For a length less than 100 ft., the quantity is found by multiplying by the distance used as a percentage. Many other diagrams and devices have been invented to aid in the calculation of earthwork quantities, and earthwork tables are available in most railroad field books, hence further discussion is unnecessary at this time.

In constructing an embankment, earthwork is frequently taken from *borrow pits* along the right of way, but the amount of such borrow can be readily calculated by methods already explained. Inasmuch as earthwork should be paid for but once, it is customary to pay for the yardage of the excavations and borrow pits without making any effort to calculate the cubature of the embankments and spoil dumps where material has been wasted along the right of way.

Earthwork expands somewhat when first loosened, but when put in embankment and compacted by passage of teams over the embankment, it actually shrinks to less volume than when in its natural bed. Clay and loam will shrink about 10 to 15 per cent while gravel and sand will shrink only about 5 or 6 per cent, and other soils are intermediate between these extremes. On the other hand, solid rock blasted from its bed and broken up will expand about 40 to 50 per cent, depending upon the degree to which it is broken up. The American Railway Engineering Association adopted the following rule as the proper allowance for shrinkage:

For green embankments, shrinkage allowance should be made for both height and width according to the following rates of decrease in volume:

1. For black dirt, trestle filling, 15 per cent.
2. For black dirt, raising under traffic, 10 per cent.
3. For clay, trestle filling, 10 per cent.
4. For clay, raising under traffic, 5 per cent.
5. For sand, trestle filling, 6 per cent.
6. For sand, raising under traffic, 5 per cent.

To allow for shrinkage, the top width and the height should be increased by such amounts that the volume will be increased by the above percentages.

Haul. As stated in a previous paragraph, the profile should be so chosen that the excavated material will just equal the embankment. This is accomplished by making the cuts and fills balance on the profile approximately. As a matter of fact, owing to the shrinkage of the earthwork and due to the fact that drainage requires a slight embankment for the track all the way, the profile should be adjusted so that the cuts would more than equal the fills. This procedure necessitates hauling the excavated material considerable distances at times, and some distance, of course, at all times. Moving the earth from the place where it is excavated to the place where it is to be deposited is called *haul*, and it is measured by the amount of earth moved multiplied by the distance moved. This product represents the work done in moving the earth since it represents the product of the force required to move the earth and the distance through which this force acts. The unit of haul is 1 cu.yd. hauled 100 ft., and is sometimes termed a *yard-station*, being a compound unit as is the unit of work, the foot-pound. The distance hauled is sometimes spoken of as the haul, but in the present discussion the term haul will be used as above defined.

The point where the subgrade passes from cut to fill is called a *grade point*, and all excavated material must be transported from the cut to this point and from this point to the place of deposit in the fill. The product of an increment of earth and the distance to the grade point represents the moment of that unit about this point as well as the haul, hence the total haul is the amount of earth in excavation multiplied by the distance between the center of gravity of the mass in excavation and the center of gravity of the mass in the embankment that it forms. Usually, if the distance hauled is less than a certain specified amount, no extra charge above that for simple excavation is made for the hauling. This distance is termed the length of free haul, and varies with circumstances, being usually about 500 to 1000 ft. The former figure obtains generally in the western part of the country while the latter is used in the eastern; the former has been adopted by the American Railway Engineering Association as the proper limit of free haul. The amount of haul (in yard-stations) above the free haul (in yard-stations) is paid for in addition to the charge for excavation, the unit price being usually 1.0 to 2.0 cents per yard-station. This extra haul is called *overhaul*.

Problems pertaining to haul can best be solved graphically by means of the *mass diagram*, or Bruckner's curve, which will now be briefly explained. It may be said, in passing, that this curve involves a principle of very wide and useful application in engineering, aside from earthwork calculations.

After the solidity or quantity for each section has been calculated, each is adjusted for shrinkage, and then the algebraic summation of quantities for all preceding sections is written opposite each section. See Table XLI. These summations are then plotted as ordinates above the corresponding stations as abscissæ and the points joined by a continuous line. See Fig. 98. The resulting curve is called the mass diagram, or Bruckner's curve, from the name of the Bavarian engineer who invented it. Lalanne, a French engineer, and various others have devised curves for accomplishing the same purpose, but Bruckner's curve seems to be the most satisfactorily and the most universally used. A study of the curve reveals the following properties:

1. The slope of the curve is positive in excavation and negative in embankment, the curve being concave upward if the solidities are becoming larger at each station, a straight line if constant, and concave downward if diminishing at each succeeding station.

2. The maximum and minimum points on the mass diagram indicate grade points on the profile. Since the section solidity is a function of the center height, the mass diagram corresponds in a sense to the first integral of the profile.

3. Excavation equals embankment between the points where a horizontal line cuts the curve.

4. " Hill " portions of the diagram, or the areas above such a horizontal line, indicate haul forward, and "valley" portions, or areas beneath such a line, indicate haul backward, in order that cuts and fills may balance between these points.

5. The area under the mass diagram represents the haul in yard-stations if the center of gravity of each section is assumed at the center.

In Fig. 98, the area between the zero axis and the mass curve represents the total haul. If the line *GK* represents the

Table LXI

CALCULATIONS FOR MASS DIAGRAM

Station.	Center Height.	Quantity in Section, Cu.Yds.	Shrinkage Factor, Per Cent.	Quantity Corrected for Shrinkage.	Summation of Quantities, Cu.Yds.
0	0	0		0	0
1	+ 2.0	+205	−10	+184	+184
2	+ 4.2	+436	−10	+392	+576
3	+ 2.1	+216	−10	+194	+770
3+30	0.0	+ 43	−10	+ 39	+809
4	− 4.8	−467	....	−467	+342
5	− 6.2	−602	....	−602	−260
6	− 5.7	−521	....	−521	−781
7	− 2.1	−200	....	−200	−981
7+40	0.0	− 66	....	− 66	−1047
8	+ 2.2	+245	−10	+220	−827
9	+ 6.1	+642	−10	+578	−249
10	+ 3.7	+384	−10	+346	+ 97
11	+ 4.1	+448	−10	+403	+500
11+50	0.0	+ 96	−10	+ 86	+586
12	− 2.4	−217	....	−217	+369
13	− 3.2	−285	....	−285	+ 84
14	− 8.3	−642	....	−642	−558
15	− 1.2	−113	....	−113	−671
15+20	0.0	− 46	....	− 46	−717
16	+ 5.7	+593	−10	+534	−183
17	+10.5	+1120	−10	+1008	+825
18	0.0	+522	−10	+470	+1295
19	− 3.2	−306	....	−306	+989
20	0.0	−107	....	−107	+882
21	+ 3.6	+387	+50	+580	+1462
22	0.0	+ 85	+50	+127	+1589
23	− 2.0	−164	....	−164	+1425
24	−11.4	−963	....	−963	+462
25	− 6.2	−512	....	−512	− 50
25+60	0.0	−201	....	−201	−251
26	+ 1.8	+206	−10	+185	− 66
27	+ 5.0	+528	−10	+475	+409
28	+ 3.0	+388	−10	+350	+759
29	+ 1.8	+212	−10	+191	+950
30	0.0	+ 87	−10	+ 78	+1028

free haul distance, then the area *FGHJKM* represents free haul for this portion and the areas *EFG* and *MLK* represent overhaul, the former area being the haul involved in collecting the material at the excavation end of the free-haul distance and the latter area being the haul involved in distributing it in the fill after being hauled the distance *GK* (free). For this case, these

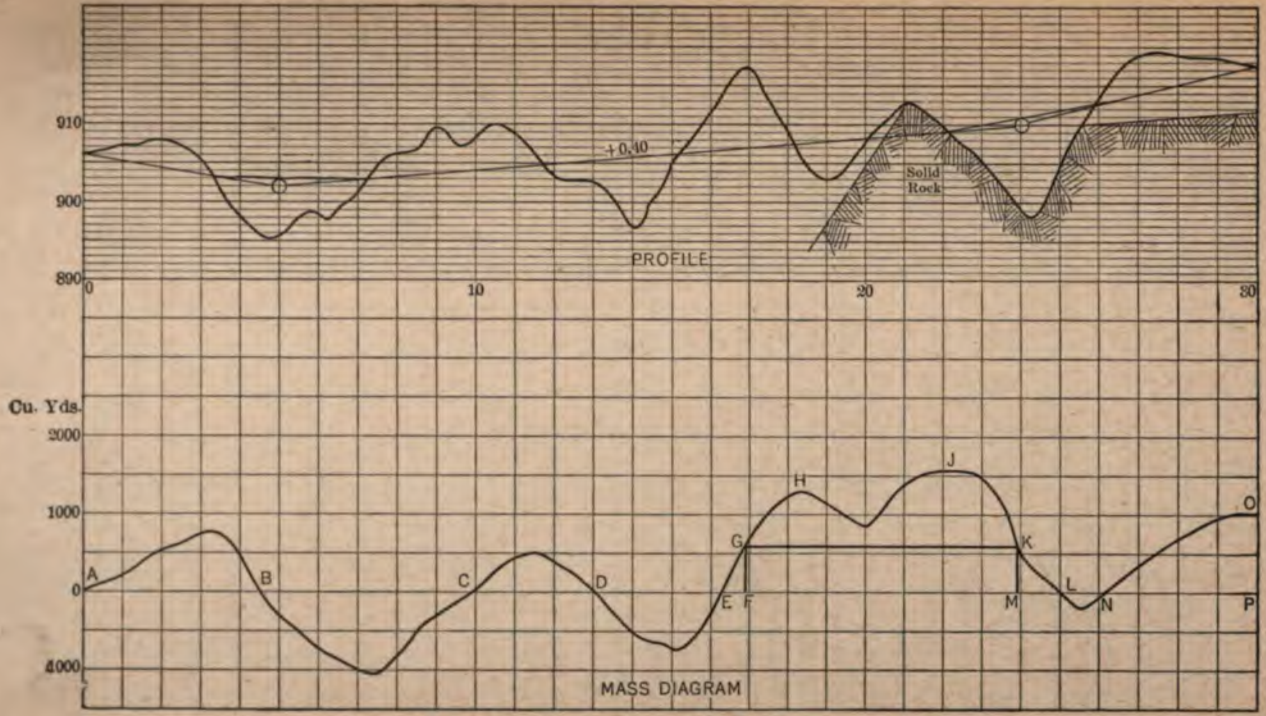


FIG. 98.—Mass Diagram for Earthwork.

areas indicate 1150 yard-stations overhaul, which, at 2 cents per yard-station, would amount to $23 as the payment for overhaul. The area *FGKM* represents the haul involved in carrying this material the length of the free haul, and the area *GHJK* represents the haul involved in handling material entirely within the limit of free haul.

Some engineers have contended that under a contract allowing for overhaul, all earthwork handled should be hauled free the specified limit of free haul, and hence, if the total haul divided by the yardage in excavation is not greater than the specified limit of free haul, no overhaul should be allowed. This is manifestly unfair, unless the construction of the contract is thoroughly understood by both parties at the time of the letting.

Fig. 99 shows on a small scale some of the uses of the diagram in determining the economic handling of haul, borrow and waste. The length of *economical haul* is the limit beyond which hauling regularly excavated material becomes more expensive than to waste and borrow. This distance is obviously found by dividing the actual cost per yard for excavating the material by the actual cost of hauling per yard-station and adding the distances that wasted and borrowed material must be transported. Thus, if the actual cost (not contract price) of excavation is 15 cents per cubic yard and the actual cost of hauling is $\frac{3}{4}$ cents per yard-station, the waste material having to be hauled 300 ft. to a spoil bank and borrow, 200 ft. from the borrow pits, then the limit of economical haul is $^{100}(15 \div \frac{3}{4})+300+200=2500$ ft.

Where the limit of free haul (f) is agreed upon as well as the price for excavation, (c) cents per cubic yard, and the price of overhaul (c') cents per yard-station, it may be well to fix the limit of maximum haul at $^{100}\left(\frac{c}{c'}\right)+f$ in order that the contractor may not avoid the expense of difficult excavation and unjustly throw the expense of such work on the railroad, and thus profit by what may be a liberal price for overhaul.

In a reversal of direction of the mass curve, placing the horizontal line so that its two segments are equal ($LM=MN$) obviously gives a minimum haul. The distance PQ represents the limit of economic haul.

Setting Track Stakes. After all grading is complete, it is necessary for the line to be run out on top of the graded road-

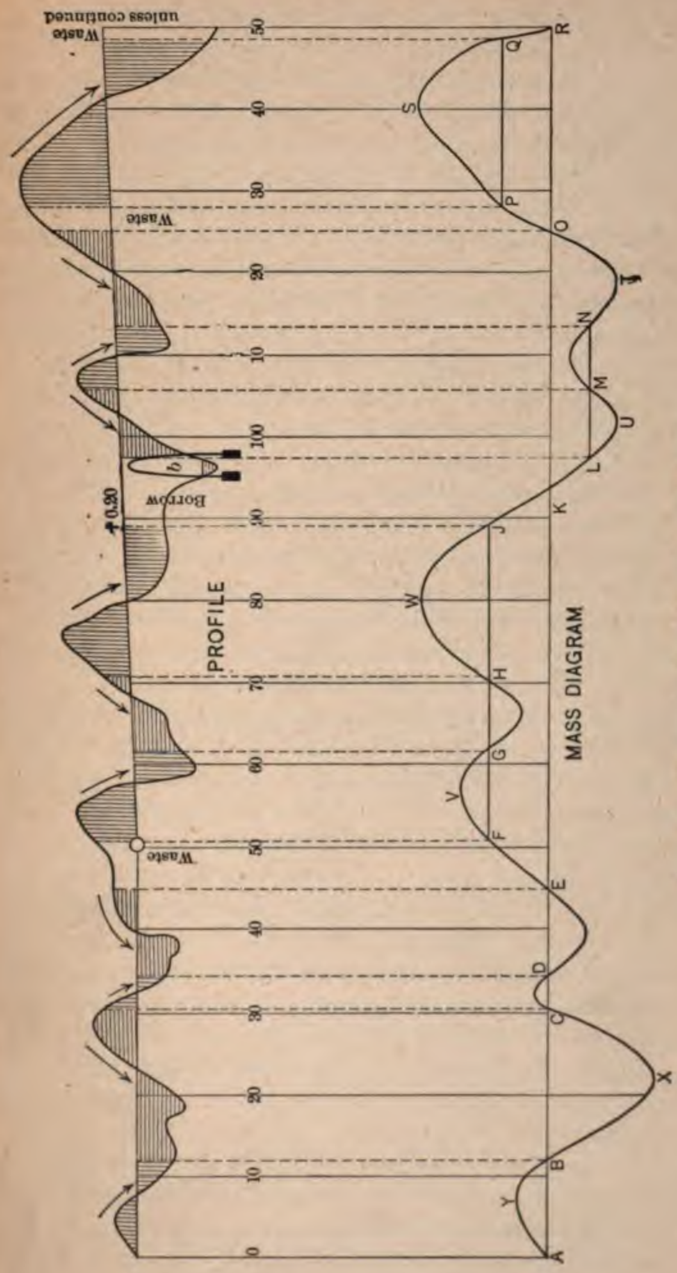


FIG. 99.—Economic Haul from Mass Diagram.

bed in order that the track can be laid with exactness. The center stakes are driven with care for this purpose and a tack is driven in each stake exactly at the point where the center of the track is to be placed. This necessitates running all curves again, but with much greater care than when only the position of the roadway depended on the accuracy of the work. Moreover, accurate work is possible in this case because the ground over which the party is working is carefully smoothed and ready to receive the track. The stakes for track centers should be 2 ins. square and 2 ft. long, and should be driven so that about 6 ins. project above the surface of the ground. They should be driven every 100 ft. on tangent and every 50 ft. on curves.

It is necessary also to set grade stakes in order that the trackmen may place the track exactly at grade. The subgrade is finished a certain distance below the proposed base of rail to allow for ballast, usually 1 to 1½ ft. Stakes 2 ins. square and about 3 ft. long are driven along the side of the roadbed and the desired elevation of the base of rail is written on the stake referenced to the top of the stake. A good method is to drive the stakes so that the base of the rail will be 1 ft. above the top of the stakes. With a level board, the trackmen can readily adjust the track to grade by means of these stakes.

Center Line and Grade in Tunnel Construction. Obviously, from the nature of the case, a tunnel cannot be staked ahead of construction. The method necessarily followed is to indicate the center line on the face wall or breast of the tunnel, allow the excavation to proceed a few yards in that direction and then give line again on the face wall. The permanent line stakes can best be driven in the roof of the tunnel and nails with eyes driven into these stakes so that the plumb bob for the transit can be suspended therefrom readily. In passing around a curve in a tunnel, the transit must be moved ahead frequently because of the intercepting of the line of sight by the inner wall, the mid-ordinate for the longest sight being half the width of the tunnel. The secret of accurate work under these conditions is frequent *checking of the line from the beginning.*

Where it is necessary to plumb down a shaft from a line on top of the ground to establish a center line at the bottom of the shaft, heavy plumb bobs weighing 15 to 25 lbs. are used. A form commonly employed for this purpose consists of a cast-iron cross about 18 ins. long, with arms 6 ins. long, and with an eye at the top for the attachment of the chord or wire, and a point at the bottom. When suspended in oil, such a plummet will become almost perfectly quiet in a comparatively short time. With two such plummets dropped from the top of a shaft, a transit set at the bottom of the shaft can readily be placed on the line established by the wires.

Elevations in tunnel construction are set in a manner similar to the mode of procedure for line points. It is necessary to follow the construction very closely lest the work progress off line or off grade.

Permanent Monuments. As soon as the track is laid, permanent monuments should be set at all positions of P. S., P. C. C. and P. T. Iron pins 1 in. in diameter and 3 ft. long are frequently used for this purpose; also, short pieces of old rail 3 or 4 ft. long are sometimes used. Some roads place these monuments at the center of the track while others place them at a definite distance from the center line where they may more easily be found and where they will be less likely to be disturbed.

Permanent bench marks should also be established about every half mile and they should be carefully referenced and described. Masonry piers, abutments, culvert parapet walls or wings, door sills of permanent buildings, and other permanent objects may be used for this purpose. If such are not available, a bench mark may be established by digging a post-hole about 3 ft. deep and filling it with concrete, or a large stone may be set in the ground. The references should be to mile-posts and to stations along the line.

Bridge Site Surveys. The survey of the site of a proposed bridge should give all necessary information for the proper design of the bridge, both substructure and superstructure. A bridge may be over (*a*) a stream or ravine, (*b*) a highway, or (*c*) another railway. The information that should be secured in such a survey includes the following:

1. Location, referred to stationing of the railroad.
2. Alignment, degree and length of curve, if on a curve.
3. Superelevation of track.
4. Position of right-of-way fences.
5. Profile of base of rail over the bridge at the proposed grade and for about 1000 ft. on either side of the proposed structure.

6. Angle that the center line of the structure makes with the stream, highway, or other railway, and the desirable angle of wing walls.

7. Profile of the ground along the center line of the track extending well past the positions of the abutments.

8. Profile of bed of stream, in case of water-way, for some distance, say 100 ft., above and below the site of the bridge. All levels and profiles should be referred to a stable bench mark, which should be very carefully and fully described in the notes.

9. Where the bridge is over a stream, the following additional data should be secured:

a. Drainage area above the bridge in order to enable the designer to estimate the proper water-way. This area should be obtained by inquiry, from maps, or by actually walking around the water-shed if small. Various methods of making rough surveys of drainage areas by means of stadia readings have been used advantageously.

b. Height of high water and date of record height if obtainable.

c. Low-water mark.

d. Evidences of change of channel, such as noting the cutting and filling banks of the stream above and below the bridge site.

e. A small scale map of the drainage area and the site.

10. In regard to foundations, the following information should be obtained:

a. Nature of the soil and an estimate of the bearing capacity.

b. Depth to solid rock or shale if within reach.

c. Necessity for use of piles.

d. Careful record of all borings, which should be made in sufficient number to indicate the nature of the foundations to be encountered.

11. When the bridge is over a highway, notation should be made of whether the undercrossing is necessary, or if it could be shifted to another location advantageously; also, the width of highway and character of the road, drainage ditches along the sides, profile of the highway, and notes on pavement, if over a city street or if the highway is surfaced.

12. Where the bridge is over another railway, note should be made of the exact intersection of the two center lines, a profile and alignment notes made of the other road, clearance necessary, and any other information that may be of special use.

Fig. 100 shows the survey notes recommended by the Amercan Railway Engineering Association.

The water-way for culverts may be computed by means of the formula proposed by Prof. A. N. Talbot.

Area of water-way in square feet, $a=CA^{\frac{3}{4}}$,

where A is the area of the water shed in acres and C a coefficient depending on the character of the drainage area, equal to 0.2 for flat prairie regions and 0.8 to 1.0 for steep precipitous slopes. The proper value for country of intermediate character must be chosen according to the judgment of the engineer. A rather extended comparison of various formulas * for calculating water-ways indicated that the above formula is the most satisfactory for general use.

Staking Out Culverts, Piers and Abutments. A similarity exists in the procedure in staking out such structures as culverts, small beam and slab bridges, and piers and abutments for large bridges. Such structures are, or should be, dimensioned on the plans to a center line or a face line and to the center line of track. When they are so dimensioned, it is only necessary for the engineer to set firm stakes with tacks in them on the center line of track and on the center line or face line of the structure at right angles to the track, or at any other angle that may be designated on the plans. The chief objective in setting such construction stakes should be to establish two reference lines on the ground that will correspond to two reference lines or axes on the drawing, so that any point or line shown on the drawing can readily be located in projection on the ground. If the drawing is properly dimensioned, this is not a difficult task.

After the structure is located in plan, elevations should be indicated on driven stakes or otherwise for the proposed top of footings, crown of arch, bridge seat, top of back wall, etc., as the case may be. Usually the points of elevation for concrete masonry above the footings are set directly on the forms ultimately, hence, these preliminary points serve chiefly as a guide in setting the forms. This is particularly true for work of considerable magnitude such that the engineer may find it advisable to watch with some care. For minor work, the points originally set may serve for the final completed work. Where triangular, molding is used for finishing the corners of bridge seats and the tops of piers: marks for placing the molding should be set directly

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* Proc. Am. Ry. Eng. Assn., Vol. VI.

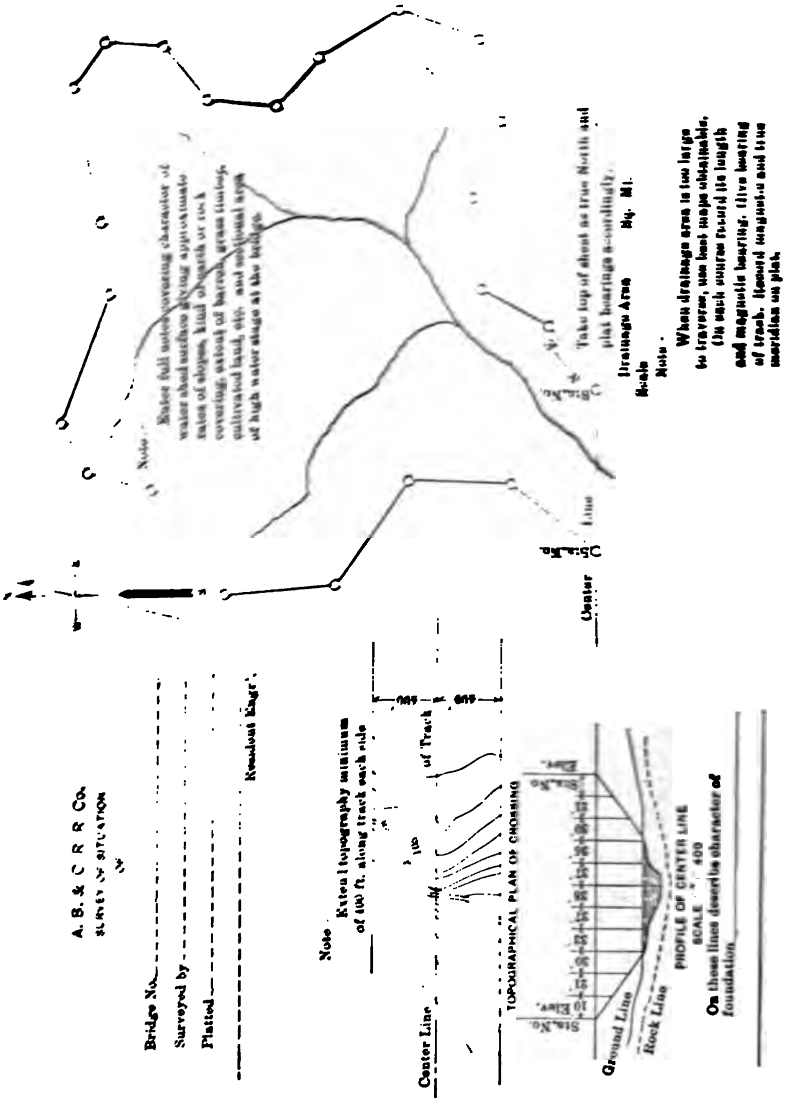
A. B. & C. R. R. Co.
SURVEY OF SITUATION
Bridge No.
Surveyed by
Platted
Resident Engr.
Note: Extend topography minimum of 400 ft. along track each side
Center Line of Track
TOPOGRAPHICAL PLAN OF CROSSING
Sta. No.
Elev.
Ground Line
Rock Line
PROFILE OF CENTER LINE
SCALE 1" = 400
On these lines describe character of foundation
Note: Enter full notes covering character of water shed surface giving approximate rates of slopes, kind of growth or rock covering, extent of barren, grass, timber, cultivated land, etc. and additional data of high water stage at the bridge.
Take top of sheet as true North and plot bearings accordingly.
Drainage Area Sq. Mi.
Scale
Note: When drainage area is too large to traverse, use best maps obtainable. On each course record its length and magnetic bearing. Give bearing of track. Record magnetic and true meridian on plat.
Center Line

FIG. 100.—Survey of Bridge Situation.

on the forms by the levelman and the molding checked by him after it is in place.

Drainage. The provisions for drainage of the roadway are so important that they should be kept under the direct supervision of the engineer. The most destructive agency to roadbed and track is improper drainage, which permits the ballast to fill with clay and in the winter causes heaving of the track due to freezing. Side ditches should be carefully constructed to a definite gradient by means of the engineer's level, and this slope should be such as to cause the water to run rapidly from the roadway. Moreover, the cross-section of the ditches should be determined to fit the conditions when an unusual amount of water may need to be removed, and then the ditches should be carefully built according to the design. The familiar sight of side ditches of varying cross-section and slope offers a ready explanation of many of the ills of track maintenance. Where tile and paved ditches are used for drainage, care should be exercised to build them carefully to grade.

On high embankments and in deep cuts, provision should be made to prevent the washing of the slopes. This is usually accomplished by digging small ditches along the slope parallel to the track in order to intercept the water as it gathers on the surface and to carry it away to the main drainage channels. Whenever a cut has higher ground above the top of the slope, a ditch should be dug along the top of the slope to intercept the water from above and thus prevent its reaching the roadway.

Water Supplies. Securing satisfactory water supplies for a railroad is a matter of foremost importance. Space does not permit an extended discussion of the question, but fortunately there are available several excellent texts on water supplies to which the reader is referred for additional information. Observations should be made on the regimen of streams that are likely to be used for water supplies and investigations made of the character of small lakes. Frequently recourse must be had to wells, in which case extended borings may be required. Such investigations should be made with care and all logs and other records of borings carefully preserved. Where gravity flow of water from the source into the tanks or to the water columns can be made available, a considerable saving is effected. Care should be exercised to secure as soft water as possible, for hard water will require treatment (See Chapter VIII). The supply at any point should be sufficiently large so that the necessary pumping can be done in a short period of time, six or seven hours, to suffice for the entire twenty-four hours' demand.

The following suggestions for water service investigations are abstracted from the Manual of the American Railway Engineering Association.

Springs should be carefully gauged for a period of at least a year. Where practicable, a reservoir should be constructed.

Lakes, natural ponds, creeks, and rivers require special investigation. The points to be considered are quantity, quality, future pollution, and riparian rights.

Dug-well construction should always be preceded by a careful auger test to determine the strata to be encountered.

Surface-pipe wells are satisfactory where local conditions permit of their use.

A chemical analysis should be made of all water and the possible cost of treatment investigated.

Progress Reports. The resident engineer will be required to make progress reports from time to time to the division engineer or to the assistant engineer, showing the status of the work on the residency, and the division engineer is required, in turn, to make progress reports to the chief engineer, showing the state of the work on the division. *Progress maps* and *progress profiles* are most commonly used for this purpose, which are prepared by making blue prints from the tracings that showed the proposed work and indicating in one color the work completed, another color the work under way, etc. The state of completion of any particular phase of the work is commonly stated in per cent; e.g., a bridge abutment may be reported at 65 per cent finished.

Cost Keeping. For many reasons, it is very desirable to keep an accurate and systematic record of cost of construction. Such data may serve to effect economy in future work and to bring about a consistent expenditure of the funds. For interstate railways, such records are required by the Interstate Commerce Commission, but these records are for the whole work, while the costs that the resident engineer should keep and analyze are for the small jobs that come under his supervision. For his own professional advancement as well as for the benefit of the company, the resident engineer should be systematic, conscientious and scientific in his methods of keeping costs.

The keynote of this work consists in arriving at unit cost, and one of the chief difficulties is securing an equitable distribution of general expenses to several items or work. An effort should be made to obtain the cost of the finished work in terms of the unit of labor and unit of materials as well as in terms of units of money. Records of this sort are of little value, however, unless they are complete and give in detail the conditions under which the work was done. The percentage of the total cost of each item should be determined and explanations noted for any abnormalities.

Care should be exercised to distinguish between the apparent cost resulting from the direct charges of materials, labor, transportation, etc., that enter directly into the cost of the finished work and the total cost including all overhead charges which have to be distributed to the work in question. Because of the fact that the overhead charges and fixed charges are not so apparent, error may result if the cost of the materials, labor, etc., be considered as the total cost.

It is impossible to outline, even briefly, the subject of cost keeping in this connection, but the reader can readily find books on this subject that will prove to be of great value.

Monthly Estimates. In order that the contractor may be paid at intervals and not be required to stand the loss of having his money tied up in the work, it is necessary to make statements from time to time of the amount of work finished by each contractor on which to base these partial payments. These statements are commonly made monthly, and are, therefore, called *monthly estimates*. In taking cross-sections for measurement of earthwork, or in making measurements of other features of the work, extreme care is not required, since the final payment will be the remainder of the contract price after all partial payments are deducted, and the final payment will be based on the completed work. However, a careful and complete record should be kept of the data submitted on the monthly estimates in order that no misunderstanding may arise at the time of final settlement. The author has always followed the custom of keeping copies, either by carbon sheets or by ink in a book used for this special purpose, of all the quantities reported as a basis for the monthly estimates.

CHAPTER XXVI

RAILROAD CONSTRUCTION ESTIMATES

Economics of Temporary Construction. Where railroads are built before the traffic at hand justifies their existence and are dependent upon the development of business, various means of economizing are followed in construction, among which may be mentioned the following devices:

Cuts are made narrower than good practice requires, thus affording insufficient space for drainage ditches at the side of the roadbed. This is, at best, a very questionable economy when the increased cost of maintenance is considered, for the actual saving is small and the increased cost of maintenance due to impaired drainage is great.

Pile trestles are built instead of masonry or steel bridges. Perhaps this is the most satisfactory source of economy of all the devices commonly used. The initial cost of timber trestles and of steel bridges as well as their respective rates of depreciation and maintenance are pretty well known from their past use and the relative economy of the two types of structures can be very well estimated.

A detour, heavy grades, switchback, or other device is sometimes used where a tunnel is ultimately intended. This is another satisfactory method of effecting an economy when needed in first construction, since the tunnel can be driven after the traffic becomes heavy enough to pay for its construction.

Narrow-gauge railroads, which were once so frequently built, are applicable economically only to mountainous districts with very light traffic.

The construction of inferior track is a very objectionable form of attempted economy. As compared with the cost of right of way and the construction of roadway, the cost of track is relatively small and a little more or less spent on this item will not greatly affect the total expenditure. Light construction usually takes the form of (1) light ties, or standard ties spaced far apart, (2) light rail, or (3) poor quality or insufficient quantity of ballast. A railroad track is in reality a composite structure and should be consistently designed so that there will not be too great demand on one element due to a deficiency in another. Light construction as outlined above causes increased tractive resistance (which may not be extremely serious on a light-traffic railway), and it also greatly increases the cost of maintenance both of roadway and structures and of equipment. Light-traffic railways, as before pointed out, should be built with a view to minimum maintenance costs, whereas heavy-traffic railways should be designed to permit traffic to be transported most economically, particularly in connection with the cost of conducting transportation. The stiffness of rails increases more rapidly than the weight, while the cost varies directly with the weight, hence the stiffness increases more rapidly than the cost. Therefore, the rigidity of the track is diminished out of proportion to the saving when light rails are used. Construction of light track is therefore an expedient of doubtful value in the way of promoting economy.

Choice of Structures. With the data available at the time of designing a new railroad, it is impossible to choose strictly according to economic principles the proper type of structure to be used in every instance, but certain general limitations may be established that may be of value. In choosing between two or more possible types of structures, a balance must be struck so that the total annual cost including fixed charges and operating expenses will be a minimum, these two factors under ordinary circumstances varying inversely with each other. Fig. 101 illustrates graphically this condition of expenditures, the sum of the two being minimum when their slopes are equal but of opposite sign. At this point the calculus requirement that the first derivative equal zero is satisfied.

The two cases of choice of structures in railroad construction that most frequently arise are between a trestle and an embankment, and between a tunnel and an open cut, so far as first cost is concerned. Formerly trestles were built almost wherever the first cost would be less than the first cost of an embankment. Mr. Wellington stated that where the depth is greater than 10 or 15 ft. the cost of a fill will be greater than the cost of a trestle. With the improved facilities for handling earthwork, and with the increased cost of timber, this height has been increased. With earthwork at 16 cents per cubic yard, and timber at $28 per M., the first cost of an embankment becomes equal to that of a trestle of five pile bents at a height of 35 ft. and to a six-pile bent trestle at 38 ft., and with steel at 4 cents per pound in place, the cost of embankment becomes equal to that of a steel trestle at about 70 ft. height. The first cost is not the correct basis of comparison, however, but the total annual cost should be compared, including the interest on the first cost, the depreciation and the maintenance cost. Instead of depreciating, an embankment appreciates in value owing to the solidifying of its contents and the sodding of its slopes. At the present time, railroads are building fills 80 to 120 ft. high rather than bridges of any sort on their main lines carrying heavy traffic. For light traffic such expensive construction would not be justified. Fills 100 ft. deep are commonly built across valleys, leaving the bridge over the stream only large enough to provide sufficient water-way to carry the floods from the drainage area above. In some instances, masonry arches are placed over the stream and the fill continued across the arches. Such construction as above described is difficult to

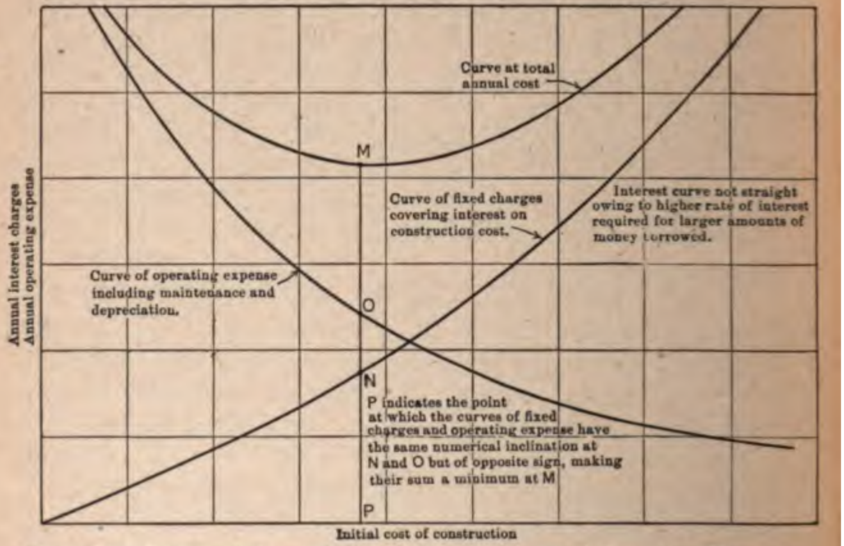

FIG. 101.—Balance between Cost of Construction and Operating Expense.

justify sometimes on strictly economic considerations, although when the indirect effects are taken into account such construction is considered good practice. Extremely high embankments or other permanent structures should not, of course, be built until all probability of future line revision is eliminated. The fact that unforeseen developments in motive power may radically change operating conditions suggests caution in the way of extremely expensive construction of a nature that would not admit of ready revision.

In a like manner, the choice between a tunnel and an open cut depends upon circumstances. If the cut is long, a tunnel may be undertaken for a less depth than where the distance is short, for when the equipment for driving the tunnel is once in place, the cost per yard of excavation is usually not more than two or three times that of open cut, and naturally the amount of material to be removed is very much less. For long distances, the economic limit of open cut is usually about 40 to 50 ft., while for piercing narrow sharp ridges it is about 60 to 75 ft. On the Chesapeake and Ohio Northern R. R.,* built in 1915–16, a "razor edge" hill was crossed with an open cut 90 ft. deep and 300 ft. long. On the same road, one cut was made that was 1200 ft. long and had a maximum depth of 95 ft. A careful analysis of the particular problem at hand should indicate the economic line of demarkation between open cut and tunnel.

At the approach or portals of a tunnel, since compressors and other equipment are already installed, it is usually economical to discontinue the open cut and begin the tunnel at a depth of 30 to 35 ft. Of course, many factors enter into the question, such as the angle of repose of the material, probability of water, and others, which render impossible exact rules, and the above figures should be considered as approximate statements.

The employment of tunnel location should be used with caution on account of increased operating expenses in many cases and on account of the high initial cost. Tunnel location has the following objections:

1. A tunnel is dark, making the engine crew less confident and making the conditions of passage unpleasant for passengers.

2. A derailment in a tunnel is almost sure to result in serious damage and loss.

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* *Eng. News*, Jan. 6, 1916.

3. The heat in long tunnels, especially those of small section, is intense and ventilation is difficult and expensive.
4. The rail is usually damp, causing the drivers to slip or requiring an excessive use of sand.
5. Conditions of track maintenance are seldom as good as outside.
6. Drainage in tunnels is almost always difficult.
7. Speed restrictions are frequently necessary through tunnels.
8. Grade revision through tunnels is difficult and expensive, hence a ruling grade through a tunnel may long remain a limiting feature.
9. Smoke and gases make operation conditions unsatisfactory.
10. The impracticability of firing up in tunnels causes a drop in steam pressure in passage.
11. In tunnels of small section, the use of helper engines is hindered owing to gases affecting the crew of the second engine.
12. Track work in tunnels is always a source of danger to trackmen.
13. Where inadequately lined, there is always danger of caving.
14. Passengers do not choose a road having many tunnels because of the disagreeable conditions, hence the passenger traffic may be decreased because of them.

On the other hand, tunnels rather than deep cuts and extensive development offer some advantages, among which may be mentioned:

1. Freedom from snow drifts.
2. Absence of trouble resulting from rock slides.

Formation of Roadway. In discussing the construction of a railroad, certain terms have been used in the preceding chapters incidentally which should be defined in this connection in order that their meaning may be clear. The American Railway Engineering Association has adopted the following definitions of terms, some of which have been used rather loosely in engineering literature.

Right of way is " the land or water rights necessary for the roadbed and its accessories," and is frequently used to designate the land actually occupied and owned by the railroad.

Roadway is the right of way prepared to receive the track. It refers particularly to the portion of the right of way between the outside limits of excavation or embankment slopes.

Roadbed is the finished *surface* of the roadway upon which the ballast and track rest.

Grade (verb) means to prepare the ground for the reception of the ballast and track, and other similar works pertaining thereto.

Grade line is the line on the profile representing the top of embankments and bottoms of cuttings ready to receive the ballast.

Subgrade is the tops of embankments and the bottoms of cuttings ready to receive the ballast. The term refers particularly to the elevation rather than to the surface.

Ballast is material placed on the roadbed to hold the track.

Track consists of the ties, rails and fastenings, with all parts in their relative position.

The formation of the roadway involves (1) clearing, (2) grubbing, and (3) grading. Clearing involves the removal from the right of way of all trees, brush and other perishable material. The material that cannot be used in ties or otherwise is either burned or removed to the side of the right of way. Clearing is paid for per acre or in units of 100 ft. square of ground actually cleared, the cost being usually about $10 to $50 per acre. Clearing should be kept at least 1000 ft. ahead of the grading in order to allow room for operations.

Grubbing is necessary for areas to be excavated, where ditches are to be placed, and under embankments so shallow that the stumps might interfere with the track. Grubbing is paid for in units of 100 ft. square or per acre and usually costs about $50 to $100 per acre.

Grading includes the formation of all excavations and embankments with the necessary transportation of material for the formation of the roadbed, ditching, diversions of roads and streams, foundation pits, borrow pits, and all similar works.

Cost of Grading. In order to fix the prices properly for handling earthwork, it is necessary to classify the materials handled. Usually three classes are recognized, viz., solid rock, loose rock, and common excavation.

Solid rock comprises rock in solid beds or masses in its original position which requires blasting for practical removing, and all detached fragments and boulders containing 1 cu.yd. or more. The price of solid rock excavation varies from 50 cents to $1.50

per cubic yard, depending upon the quantity to be excavated and the manner of doing the work.

Loose rock consists of rock, whether in its natural bed or not, that can properly be removed by pick and shovel, although steam shovel and light blasting may be utilized to facilitate the work. The cost of excavating loose rock varies from 25 cents to 50 cents per cubic yard.

Common excavation includes all other material, such as earth, sand, gravel, etc. The cost of grading in common excavation depends upon the conditions and methods of doing the work and varies from 15 to 24 cents per cubic yard for railroad work. Fig. 102 shows the effect of the methods employed on the cost per cubic yard, the curves being plotted from data given in the *Engineering Record*, November 21, 1914.

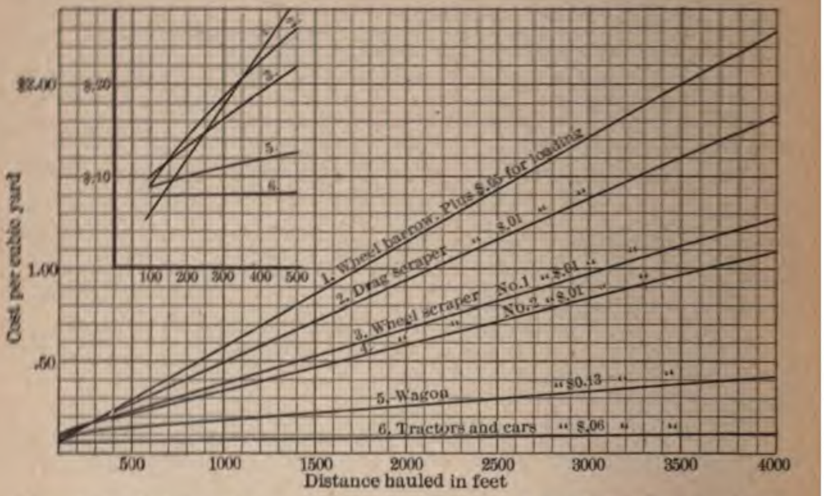

Fig. 102.—Relative Economy of Various Methods of Handling Materials.

Standard Roadway. The American Railway Engineering Association has adopted the following dimensions for roadway, the width of roadbed being constant in both cut and fill:

Class A roads	width 20 ft.
B	16
C	14

Excavations must be made wide enough, however, to provide for a drainage ditch at either side of the roadbed. The track is considered as resting on a low embankment through the cut, and in order to preserve uniformity the subgrade is maintained at constant width.

Class A includes those districts having heavy traffic, that is, a freight car mileage of more than 150,000, or a passenger car mileage of more than 10,000 per mile of line per year, and with maximum speed of passenger trains of 50 miles per hour.

Class B includes all roads or districts carrying a medium traffic, viz., a freight-car mileage of more than 50,000 and a passenger-car mileage of more than 5000 per mile per year, with maximum passenger train speed of 40 miles per hour.

Class C comprises those districts with light traffic, that is, less than Class B.

The side slopes to be adopted depend upon the nature of the soil material and the climatic conditions where the road is being built. Excavations in arid regions will stand at a steeper slope than in humid regions. Ordinarily the following slopes will be found satisfactory:

Embankments.
  Earth, 1½ to 1.
  Loose rock and gravel, 1¼ to 1.
  Rock from excavations, 1 to 1, or ½ to 1.

Excavations.
  Earth, 1½ to 1.
  Loose rock, 1 to 1, or ½ to 1.
  Solid rock, ½ to 1, or vertical.

The natural slope of earth where erosion has been unhindered except by vegetation is almost always flatter than 1½ to 1, but embankments are built with the expectation of being protected from serious erosion. Embankments formed of sand are commonly covered on the sides for a depth of about 2 ft. with earth.

Pile and Frame Trestles. In new construction, recourse is almost always had to pile trestles for carrying the track across ravines where more permanent construction would require steel or masonry bridges, or an embankment and a culvert. Pile trestles have made possible the building of American railroads, although on well-established roads they are being replaced by more permanent structures. Timber trestles have the following merits for initial railroad construction:

1. A well-built trestle is a solid structure and will last a reasonable length of time.

2. A trestle affords an opportunity to observe the flood conditions of the stream crossed with a view to determining accurately the size of water-way required.

3. The permanent structures, either of masonry or of steel, can be built later at a reduced cost owing to the improved transportation facilities.

4. The period of construction is much shortened, thereby putting the line into operation and decreasing interest charges during construction.

5. The trestles can be used directly to facilitate the construction of embankments which may replace them, for the trestle fill is an approved method of embankment construction.

The cost of trestles naturally varies with the locality, the cost of timbers and other materials, and the cost of labor. The amount of bracing and the length of piles is determined by the height of the trestle, and consequently the cost varies with the height of the structure. The following formulas for the amount of materials in timber trestles were deduced from work done on the Northern Pacific Ry.* M represents the thousands of feet of timber in single-track trestles per foot of length, H the height in feet to the bottom of the deck, and L the length of the trestle in feet.

$M=220+6H$, for heights up to 25 ft.
$M=240+8H$, for heights 25 to 60 ft.
$M=240+9H$, for heights 50 to 75 ft.
$M=240+10H$, for heights 75 to 125 ft.

Where the trestle is low, H may be taken as the average height, but where there is considerable variation in the height, it is better to estimate the trestle in sections. For framing, the cost of labor will be about 50 per cent of the cost of the timber ordinarily. About three man-days of labor should be counted on per 1000 ft. of lumber for framing and erecting the bents.

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* Gillette's "Handbook of Cost Data," p. 966.

About 70 lbs. of wrought iron and 30 lbs. of cast iron are required per 1000 ft. of timber in a trestle. Fig. 103 gives the material in framed timber trestles on the Chicago, Milwaukee and St. Paul Ry.

The following equations give the approximate cost of pile trestles where timber is \$28 per M., labor \$12 per M. feet of timber handled, iron 4 cents per pound and piling 35 cents per foot in place:

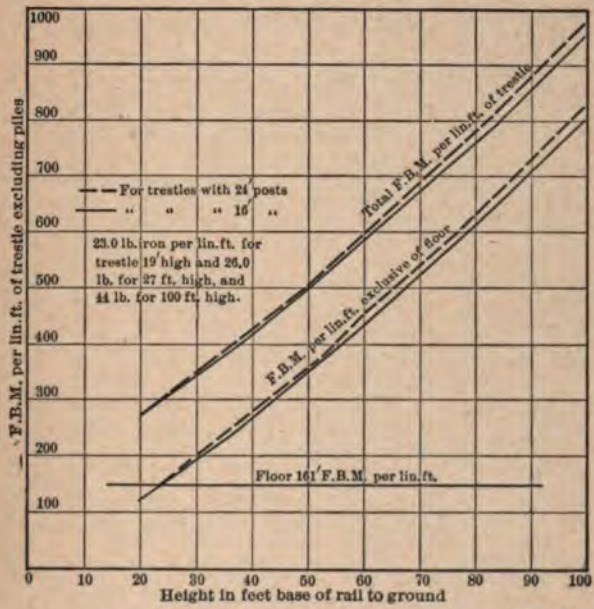

FIG. 103.—Quantities of Materials in Pile Trestles on C., M. & St. P. Ry.

Five-pile bents, open deck, $C = 25 + (7 + 0.2H)L.$
Five-pile bents, ballast deck, $C = 30 + (12 + 0.25H)L;$
Six-pile bents, open deck, $C = 30 + (8 + 0.2H)L;$
Six-pile bents, ballast deck, $C = 30 + (14 + 0.25H)L,$

C being the total cost in dollars, H the height in feet, and L the length in feet. The use of creosoted timber added 10 to 15 per cent to the cost.

The life of pile and timber trestles depends upon climatic conditions to a considerable extent. In the arid and semi-arid regions they will last probably 25 to 30 years, while in the more humid regions their life is much reduced.

Masonry Structures. The principal masonry structures connected with railroad construction are retaining walls, culverts, arch bridges, bridge abutments and piers, although masonry may be used in a number of minor accessory structures, including tunnel linings, buildings, etc.

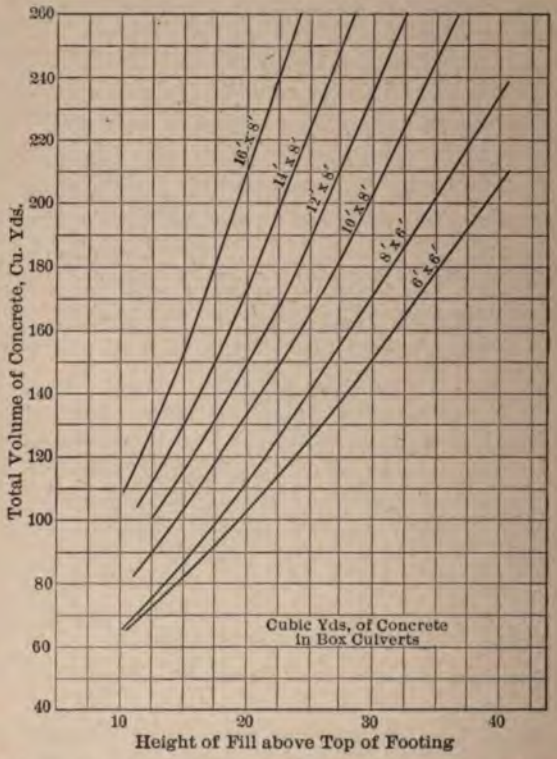

FIG. 104.—Quantities of Concrete in Reinforced Concrete Box Culverts on the C. M. & St. P. Ry.

The cost of retaining walls depends greatly upon the type of construction. Stone masonry of the class generally used commonly ranges in price from $6 to $10 per cubic yard, plain concrete $4 to $6, and reinforced concrete from $6 to $12. Of course, a close estimate would require a careful analysis of quantities required and a study of the unit prices applicable.

A culvert is a masonry bridge of short span that provides a water-way or other necessary opening through an embankment. The transverse length depends upon the height of the embankment above the culvert, also upon the height of the parapet wall, and the grade of the culvert along the center line of the water-way. The reinforcing of reinforced concrete culverts averages about 50 lbs. of steel per cubic yard of concrete. Fig. 104 gives the yardage of concrete required for box culverts and Fig. 105 gives the yardage of concrete and the weight of steel required for reinforced concrete arch culverts of various sizes built by the C., M. & St. P. Ry.

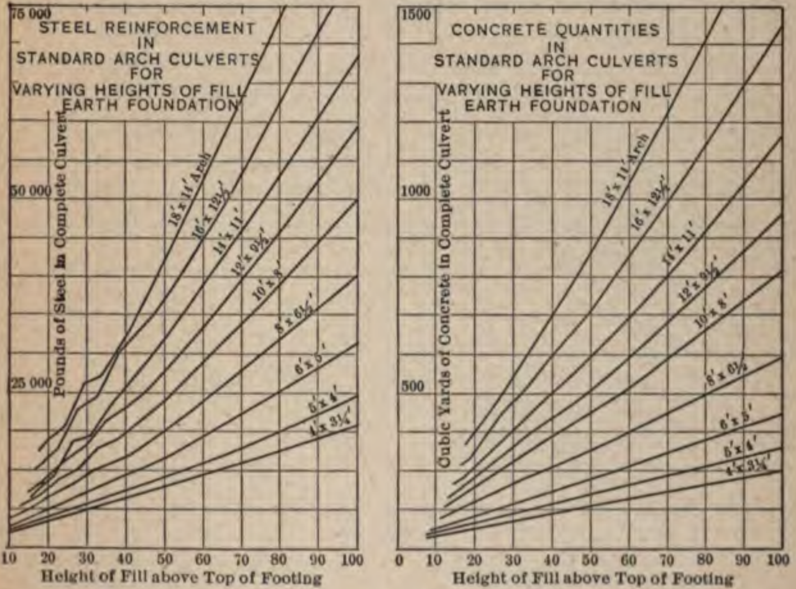

FIG. 105.—Quantities of Concrete and Steel in Reinforced Concrete Arch Culverts on the C., M. & St. P. Ry.

A bridge pier is a structure whose function is to support the adjacent ends of two spans of a bridge, and it must be able to sustain the vertical dead and live load, traction forces on the superstructure, wind effect on the bridge and on passing trains, centrifugal force where on a curve, and the impact and pressure due to ice and drift in the stream. Piers may be classified as

1. Pile piers.
2. Steel cylinders.
3. Pedestals or low piers supporting columns.
4. Mass piers of stone or of plain concrete.
5. Reinforced concrete piers.
   - *a.* Solid.
   - *b.* Hollow.

The cost of piers varies greatly and can best be estimated from the cubature of the masonry, the cost varying from $6 to $10 per cubic yard.

An abutment is a structure whose function is to support the end of the superstructure of a bridge, to retain the embankment carrying the roadbed, to provide support to the track in passing from the earth roadbed to the bridge floor, to withstand a large portion of the tractive forces exerted on the bridge and to protect the embankment against scour. Abutments may be classified as follows:

1. Pile abutments.
2. Steel cylinder abutments.
3. Mass abutments of stone or of plain concrete.
   - *a.* Wing abutments.
   - *b.* U-abutments.
   - *c.* T-abutments.
4. Reinforced concrete abutments.
   - *a.* Counterfort wing abutments.
   - *b.* U-abutments.
   - *c.* Arch abutments.
   - *d.* Trestle abutments.

Mr. J. H. Prior,* Engineer of Design, C., M. & St. P. Ry., gives the cost of various types of bridge abutments as shown in Fig. 106. His general conclusion is that for high fills, the reinforced concrete abutment is more economical than the mass abutment.

The cost of bridge substructure depends very greatly upon the facility with which a satisfactory bearing for the piers and abutments is obtained. For large structures, it is usually desirable to sink the foundations to solid rock, or to other stable

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* Proc. Am. Ry. Eng. Assn., Vol. XIII, p. 1085.

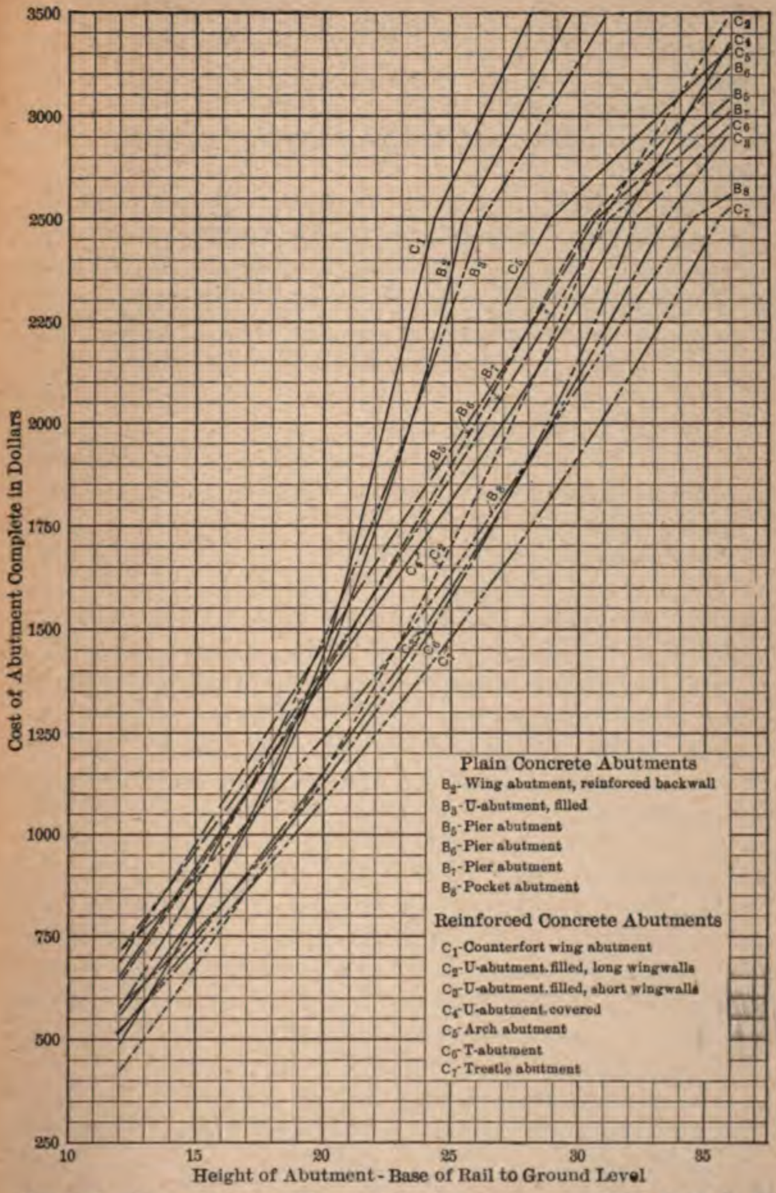

FIG. 106.—Cost of Various Types of Bridge Abutments, C., M. & St. P. Ry.

material. To do this often requires special processes that may constitute a considerable portion of the cost of the substructure.

Piles are driven where the soil is compressible and incapable of supporting the load with any reasonable spread of footings. The cost of piles driven is about 20 to 35 cents per linear foot of piles.

In water and in semi-fluid soils, special means of securing a solid foundation must be adopted and the method of procedure depends largely upon the depth below the water line to which the foundation must be sunk. The following limits indicate roughly average practice in this respect, although other considerations beside depth may cause a wide variation from these limits:

0– 10 ft., timber sheet piling.
10– 30 ft., timber or steel sheet piling, and cofferdam.
20– 50 ft., steel sheet piling cofferdam.
40– 60 ft., open caissons, or pneumatic caissons.
50–115 ft., pneumatic caissons.

The cost of such foundations varies from $10 to $20 per cubic yard of masonry below the surface.

Steel Bridges. Where streams are to be crossed that require a span of more than about 100 ft., truss bridges are commonly used, plate girders being employed for spans shorter than this, although deck girders up to 110 and 115 ft. are not uncommon. For very short spans, I-beams instead of plate girders are sometimes used, especially where shallow floors are desired. For crossing ravines where short spans may be employed, steel trestle towers with plate-girder spans are usually employed. The cost of steel work of this sort can be estimated from current prices, amounting usually to $3\frac{1}{2}$ to $4\frac{1}{2}$ cents per pound in place. The weights of different types of steel bridges may be estimated approximately by the following formulas:

Through-plate girder, open floor, $w=700+13S$;
Deck-plate girder, open floor, $w=550+8S$;
Deck-plate girder, concrete and ballasted deck, $w=400+10S$;
Pin-connected truss span, $w=1000+10S$,

w being the weight per foot of length and S the span in feet. Riveted truss spans are approximately 50 per cent heavier than pin-connected for similar spans. The weight of steel trestle towers may be expressed approximately by the formula, $W = 1400H + 70{,}000$, where W is the total weight in pounds and H the height in feet to the top of the tower. These weights are for rolling stock comparable to Cooper's E50 loading. For E55, the weights should be increased about 3 per cent, and for $E45$, diminished a like amount.

Ballast and Track. The function of the ballast is (1) to provide a medium for spreading the foundation under the ties, (2) to facilitate drainage so as to prevent heaving due to frost and softening due to mud, (3) to grip the ties so as to hold the track in place both laterally and longitudinally, and (4) to afford a convenient means of keeping the track accurately lined and surfaced. The amount of ballast required depends upon the construction, amounting on first-class construction to about 3000 cu.yds. per mile of track.

The function of the ties is to form a bearing for the rails by distributing the concentrated loads over a width equal to the length of the ties. The price of ties varies for different localities and with the grade of ties. First-class ties, 7 ins. by 9 ins. by 8½ ft. long, cost about 75 cents each, while first-class ties, 6 ins. by 8 ins. by 8 ft. long, cost about 60 cents each.

The quantities of materials per mile of track are indicated in Table LXII. The prices of these may be obtained from current price lists in engineering periodicals. Angle bars (24 ins.) for 80- and 90-lb. rails weigh about 64 to 72 lbs. per pair.

TABLE LXII

REQUIREMENTS FOR ONE MILE OF TRACK

Tie Centers, Ins.	No. Ties per Mile.	No. Tie Plat's per Mile.	FOUR SPIKES TO TIE		SIX SPIKES TO TIE.		L'gth Rail, Ft.	No. Rails per Mile.	No. Splice Bars per Mile.	NO. BOLTS PER MILE.		FENCE POSTS.	
			No. Spikes.	No. Kegs.	No. Spikes.	No. Kegs.				Four Hole Splice	Six Hole Splice	Foot Apart Ft.	No. One Side.
24	2640	5280	10,560	31	15,840	47	20	528	1056	2112	2168	8	660
23	2755	5510	11,020	33	16,530	49	22	480	960	1920	2880	12	440
22	2880	5760	11,520	34	17,280	51	24	440	880	1760	2640	14	377
21	3017	6034	12,068	36	18,102	54	26	407	814	1628	2442	16	330
20	3168	6336	12,672	38	19,008	56	28	378	756	1512	2268	16¼	320
19	3335	6670	13,340	40	20,010	59	30	364	728	1456	2184	18	293
18	3520	7040	14,080	42	21,120	63	33	326	652	1304	1956	19	278

Figures for 33 ft. and 30 ft. rails., splices and bolts based on 10 per cent in rails down to 24 ft.

The cost of laying track and placing the ballast depends upon the type of construction and the methods used. Laying by hand costs from $175 to $250 per mile, while laying by machinery costs from $125 to $175 per mile. The labor on turnouts is usually about $25 each. The following prices give an approximate notion of costs of track material:

Ballast, crushed rock, 50 to 75 cents per cubic yard. Gravel 35 to 60 cents.

Ties, good quality, 70 cents each.

Rails, Bessemer, $28 per ton; open hearth, $30 per ton.

Spikes, 2 cents per pound.

Angle bars, 1.5 cents per pound; tie plates, same.

Track bolts, 2.4 cents per pound; nutlocks, same.

On p. 488 is given the form of the American Railway Engineering Association for estimating the cost of railroad construction.

Original Cost of Great Northern Railway. The data on p. 487 represent the original cost of the Great Northern Railway, 488 miles in length, and are considered typical of such work.

Résumé. In the foregoing chapters an attempt has been made to outline the principles governing the economical design of a railway location. With certain conditions of traffic and topography given, the problem is to design the transportation plant that will handle the business most economically. The idea expressed by the equation $\frac{R-E}{C}=p$ has been retained as fundamental. The per cent earnings, p, must be made as large as possible, and it will be increased by increasing the revenues, R, by decreasing the expenses, E, or by decreasing the capital invested, C. The solution involves a consideration of (1) capital and fixed charges, (2) rates and revenues and the conditions affecting the same, (3) the characteristics of the motive power employed, its limitations and possibilities, (4) the resistance to be overcome, (5) an analysis of operating expenses in order that the effect of various changes in location may be estimated, (6) train operation and rolling stock characteristics, (7) the effect of grades on train-loads and on train operation generally, (8) the effect of minor details of distance, rise and fall, and curvature on revenues and operating expenses, (9) the choice of single or double track, (10) methods of obtaining the data on which the design is based and the procedure in locating and constructing the

Original Cost of Gt. Northern Ry. in Washington*

Item.	Cost per Mile of Line.
1. Engineering	$ 1,319
2. Right of way	4,056
3. Real estate	230
4. Clearing and grubbing	1,098
5. Grading	11,343
6. Tunnels	5,624
7. Masonry	942
8. Cribbing and bulkheading	714
9. Bridges and culverts	4,318
10. Cattle guards, road crossings and signs	234
11. Ties	1,198
12. Rails	5,932
13. Rail fastenings	774
14. Frogs, switches, etc	169
15. Tracklaying and surfacing	532
16. Ballasting	1,988
17. Surfacing, filling and lining track	61
18. Transportation department buildings	615
19. Road department buildings	88
20. Round houses and shops	328
21. Fuel and water stations	258
22. Docks, wharves and inclines	44
23. Columbia River incline	122
24. Other buildings and structures	25
25. Fences	22
26. Telegraph	47
27. Shop tools and machinery	96
28. Protection against ice and snow	158
29. Locomotive and car service	86
30. General expense	108
31. Transportation men and materials	92
32. Insurance	1
33. Operating expense	514
34. Interest on advances	501
35. Bond expenses	74
36. Bond interest during construction	1,569
37. Wagon roads	32
Total	$44,412

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[*] *Engineering-Contracting*, Dec. 8, 1909.

Size 8 x 13 inches

Form M. W. 2100

ESTIMATE FOR TRACK CONSTRUCTION

A. B. & C. R. R. Co.___

TRACK ESTIMATE__________ DIVISION

Work__________

__________ At __________

Date of Estimate__________ 19_

Total Length of Track in Ft.__________

Total Clearance Length__________ Ft.

Maximum Curvature __________ Degrees__________ Min.

Width of Roadbed on Fills__________ Ft. in Cuts__________ Ft.

Maximum Grade Away From Main Track __________ %

Maximum Grade in Direction of Main Track __________ %

Made by

____

(Title)

ITEM	DESCRIPTION	AMOUNT	UNIT PRICE	COST	CREDITS FOR OLD MATERIAL	Chargeable to:
Waylands	Acres	Ac.				
Clearing	Square (100 Ft. x 100 Ft.)	Sq.				
Moving Track		Ft.				
" Buildings						
" Fence	Kind	Rods				
Grubbing	Square (100 Ft. x 100 Ft.)	Sq.				
Grading	Cu. Yds. of	Cu. Yds.				
Pipes Kind	Size	Lin. Ft.				
Drain Tile "	"					
Culverts "	"					
Bridges "		Lin Ft.				
Ties "	(Class) Treated					
"	" "					
Rail	Lbs. per Yd.	Tons				
"	" " "					
"	" " "					
Angle Bars	Class Lb. Length	Pairs				
" "	" " "	"				
" "	" " "	"				
Bolts	Size	Kegs				
"	"	"				
Nut Locks Kind		Boxes				
Spikes		Kegs				
Rail Braces						
Tie Plates						
*Ballast (in Place)	Quarry Pit	Cu. Yds.				
†Turnouts Complete						
" "						
" without Switch Ties						
" " " "						
Switch Ties	For No. Turnout	Sets				
" "	" " "	"				
Slip Switches	Wt. Lb. No.					
Derails Complete	Kind					
Railroad Crossings	Wt. Lb. Style					
Railroad Crossings Timbers		Ft. BM				
Cattle-Guards (state kind)		Sets				
Road Crossings		Ft. BM				
Signs (state kind)						
Fences (state kind)		Rods				
Wing Fences		Pairs				
Interlocking						
Telegraph and Telephone						
Signals						
Battery Wells						
Paving Kind		Sq. Yds.				
Sewers "	Size					
Water Mains "	"					
Fire Hydrants "	No. of Nozzles					
Man Holes	Size					
Catch Basins	"					
Bumping Posts	Style					
Tunnels						
Labor (state character)						
" " "						
Handling Material						
Freight on "						
	Totals					
Eng'r and Supt.						
	Estimated Gross Cost					
	Less Credits					
	Net Estimated Cost					
	The Expense is Chargeable to					
	Maintenance Account					
	Betterment					
	Additions					

*State kind of Ballast and Quarry or Pit from which it is to be taken if possible.

†Use item, Turnouts Complete, in estimate for track, to be paid for entirely by this Company.

Drafting File Reference__________ Letter File Reference..........

plant as designed. None of these subjects has been treated exhaustively, but rather in outline. If the relative significance and importance of the factors involved have been indicated, the necessity of rational design in each case demonstrated, and the method of procedure suggested, the intent of the author has been realized.

APPENDIX A

SPECIFICATIONS FOR FORMATION OF THE ROADWAY *

GENERAL

Alignment.

1. The center of the roadway shall conform in alignment to the center stakes.

Subgrade.

2. The grade-line on the profile denotes subgrade, and this term indicates the tops of embankments or the bottoms of excavations ready to receive the ballast.

Cross-section.

3. The roadway shall be formed to the section, slopes and dimensions shown upon the standard drawings, or as may be directed from time to time.

Width of Roadway.

4. When finished and properly settled the road shall conform to the finishing stakes and shall be of the following dimensions at subgrade for single track, viz.:

On embankments........................(........) feet wide, and in excavations........................(........) feet, exclusive of the width necessary for ditches. For each additional track an additional width of.................... (........) shall be made.

Slopes.

5. The slopes of embankments and excavations shall be of the following inclinations as expressed in the ratio of the horizontal distance to the vertical rise:

Embankments,	Earth—one and one-half to one;
	Rock—from one to one, to one and one-half to one;
Excavations,	Earth—one and one-half to one;
	Loose rock—one-half to one;
	Solid rock—one-quarter to one.

These ratios may be varied according to circumstances, and the slopes shall be made as directed in each particular case.

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* Manual American Railway Engineering Association.

CLEARING

Extent of Clearing.

6. The right-of-way and station grounds, except any portions thereof that may be reserved, shall be cleared of all trees, brush and perishable materials of whatsoever nature.

Disposal of Brush, etc.

7. All these materials, except as hereinafter mentioned, shall be burned or otherwise removed, as may be directed, and without injury to adjoining property.

Stumps.

8. Where clearing is to be done, stumps shall be cut close to the ground, not higher than the stump-top diameter for trees twelve (12) ins. and less in diameter, and not higher than eighteen (18) ins. for trees whose stump-top diameter exceeds twelve (12) ins., except between slope stakes of embankments, where stumps shall be cut so that the depth of filling over them shall not be less than two and one-half (2½) ft.

Clearing in Advance.

9. The work of clearing shall be kept at least one thousand (1000) ft. in advance of the grading.

Cutting and Piling Wood.

10. All trees which may be reserved shall be stripped of their tops and branches, made into ties, or cut to such lengths as may be directed, and neatly piled at such places on the right of way as may be designated, for which service payment shall be made by the tie, or by the cord of one hundred and twenty-eight (128) cu.ft.

Isolated Trees, Buildings, etc.

11. Where isolated trees, or where buildings exist, payment shall be made for the removal thereof at a price to be agreed upon before removal.

Measurement.

12. Measurement of clearing and payment for the same shall be by units of one hundred (100) ft. square, or fraction thereof, actually cleared.

GRUBBING

Extent.

13. Stumps shall be grubbed entirely from all places where excavations occur, including ground from which material is to be borrowed as

well as from ditches, new channels for water-ways and other places where required.

Grubbing shall also be required between the slope stakes of all embankments of less than two and one-half (2½) ft. in height.

Grubbing in Advance.

14. The work of grubbing shall be kept at least three hundred (300) ft. in advance of grading.

Measurement.

15. Measurement of grading shall be estimated upon all excavation actually done, and the space to be covered by all embankments of less than two and one-half (2½) ft. in height. Payment for the same shall be by units of one hundred (100) ft. square, or fraction thereof, actually grubbed.

GRADING

16. The term "Grading" in these specifications includes all excavations and embankments for the formation of the roadbed, ditching, diversions of roads and streams, foundation pits, and all similar works pertaining to the construction of the railway, its side tracks and station grounds.

Work Included—Classification.

17. All material excavated shall be classified as "Solid Rock," "Loose Rock," "Common Excavation," and such additional classifications of materials as may be established before the award of the contract.

Solid Rock.

18. "Solid Rock" shall comprise rock in solid beds or masses in its original position which may best be removed by blasting; and boulders or other detached rock measuring 1 cu. yd. or over.

Loose Rock.

19. "Loose Rock" shall comprise all detached masses of rock or stone of more than 1 cu.ft. and less than 1 cu.yd., and all other rock which can be properly removed by pick and bar and without blasting; although steam shovel or blasting may be resorted to on favorable occasions in order to facilitate the work.

Common Excavation.

20. "Common Excavation" shall comprise all materials that do not come under the classification of "Solid Rock," "Loose Rock," or

such other classifications as may be established before the award of the contract.

Finishing Slopes.

21. Slopes of all excavations shall be cut true and straight, and all loose stone in the slopes shall be removed.

Excavation Below Subgrade.

22. Rock excavation shall be taken out .... (........) ins. below subgrade and refilled to subgrade with approved material.

Excess Excavation and Slips.

23. Excavation in excess of the authorized cross-section, as well as slides extending beyond the slope lines, shall not be paid for unless due to causes beyond the control of the contractor or his agents. In all cases the surplus material shall be removed by the contractor without delay and the slopes reformed. The classification of the material shall be in accordance with its conditions at the time of removal, regardless of prior conditions. The measurement of the material shall be the original space occupied regardless of the classification.

Disposal of Excess Excavation.

24. Where the quantity of excavation exceeds that required to make the embankment to standard cross-section, the surplus shall be used to widen the embankments uniformly, along one or both sides, as may be directed, and no material shall be deposited in waste banks unless such waste be indicated on the profiles or by written order.

Waste Banks.

25. Where wasting is ordered the material shall, if possible, be deposited below grade line, and under no circumstances shall the waste bank have its nearest edge within .... (........) ft. of the slope stakes of the cutting.

Borrow Pits.

26. Where the quantity of excavation from the cuttings of standard cross-section is insufficient to form the embankments, the deficiency shall be made up by widening the cuttings on one or both sides of the center line, as may be directed. No material shall be taken from borrow pits, unless such borrow be indicated either on the profiles or by written order.

Approximate Quantities Shown.

27. The classification and quantities shown on the profile exhibited for distribution of material are approximate only, and shall in no way

govern the final estimate. The company reserves the right to increase or diminish the quantities given without affecting the contract unit prices for the various parts of the work.

Reserving Gravel.

28. Gravel, stone or other material suitable for special use of the company, which is found within the excavations, shall, when required, be reserved and deposited in convenient places on the right of way, as directed. Other suitable material in the vicinity shall be substituted, as required, to complete the embankments.

✓**Berme in Rock Cuttings.**

29. A berme .... (........) ft. shall be left between the top of slope of rock cuttings and the top of the slope of the overlying earth.

Intercepting Ditches.

30. Intercepting ditches, when ordered, shall be made at the top of the slopes of all cuttings where the ground falls toward the top of the slopes. These ditches must diverge sufficiently to prevent erosion of the adjoining embankment. The cross-sections and locations of such ditches shall be designated. If required, they shall be excavated in advance of opening the cutting.

Ditches in Cuttings.

31. Ditches shall be formed at the bottoms of slopes in cuttings, according to cross-sections shown upon the plans, or such modifications thereof as may be directed. They shall be neatly made, clear of obstruction, and at the lower ends must diverge sufficiently to prevent erosion of the adjoining embankments.

Subdrains.

32. Subdrains of tile shall be constructed of the size and at the location directed. Trenches for these drains shall be taken out at least .... (........) ins. below the frost line; the tile shall be laid on a bed which shall be true, with half-round sections, with a filling of at least .... (........) ins. of cinders or other suitable material on either side and above the tile, and then covered with ordinary soil to the top of the trench.

Unsuitable Material.

33. Excavation incident to the construction of the roadbed, ditches, channels and roadways shall be used in forming the embankments. Frozen or other unsuitable material shall not be permitted to enter into their composition.

Formation in Layers.

34. When directed, embankments shall be built in horizontal layers of .... (........) ft. in thickness. These layers shall be of the full width of the embankments and built to the true slope, and not widened with loose material from the top. The most suitable material shall be reserved for finishing the surface; large stones shall not be permitted within a depth of at least .... (........) ft. below subgrade.

Shrinkage.

35. Embankments shall be carried to such height above subgrade and to such increased width as may be deemed a necessary provision for shrinkage, compression and washing. As the embankments become consolidated their sides shall be carefully trimmed to the proper slopes and they must be maintained to their proper height, dimensions and shape until the work is finally accepted.

Embankments on Slopes.

36. Where an embankment is to be placed on sloping ground, the surface shall be deeply plowed or stepped. Whenever directed, boggy or unstable material shall be excavated so that the embankment shall be on a firm foundation.

Embankments Across Swamps.

37. In crossing bogs or swamps of unsound bottoms for light fills, a special substructure of logs and brushwood may be required, the logs forming this foundation to be not less than six (6) ins. in diameter at the small ends. If necessary, there shall be two or more layers crossing each other at right angles. The logs of each layer shall be placed close together, with broken joints, and covered closely with brush. The bottom layer shall be placed transversely to the roadway, and shall project at least five (5) ft. beyond the slope stakes of the embankment.

Measurement and payment for this substructure shall be by units of one hundred (100) ft. square, or decimal thereof, of area covered by each layer.

Filling Trestles.

38. In forming embankments from trestles, the material shall be thoroughly compacted between the trestle bents and around and under all parts of the structure. In case of train filling from a temporary trestle, the material shall be uniformly spread in the fill.

Embankments at Trestles.

39. Embankments abutting the ends of trestle bridges shall be brought forward upon the structure a distance of at least .... (........) ft. in order to form a full roadbed.

Finishing Subgrade.

40. The subgrade shall be compact and finished to a true plane, thus leaving no depression that will hold water.

Embankments over Masonry.

41. Material for embankments over or about masonry or other structures shall be deposited in thin layers, and each layer carefully tamped. Special care shall be exercised that no excessive strain be placed upon these structures. Only the best material shall be permitted for the purpose of such filling. The contract price for excavation shall cover the cost of obtaining, distributing and packing the material behind, over and around such structures.

BORROW PITS

Land Provided.

42. Land for borrow pits or waste banks shall be provided by the railway company.

Drainage.

43. Borrow pits shall be connected with ditches and drained to the nearest water course, when required. Unless directed, material shall not be borrowed to a depth to prevent proper drainage.

Slopes and Bermes.

44. Side slopes of borrow pits on the right of way shall be the same as used in the cross-section of the adjoining roadway. A berme of not less than .... (........) ft. in width shall be left between slope stakes of the embankment and the edge of the borrow pit. A berme of not less than .... (........) ft. shall be left between the outside slope of the borrow pit and the right of way line. Bermes shall consist of the original unbroken ground.

Cross-sectioning of Pits.

45. Borrow pits shall not be excavated before they have been staked out. Borrowing must be done in regular shape in order to admit of ready and accurate measurement. Borrowing or wasting of material will not be permitted on land set apart for station grounds or for other special purposes, except by written directions.

PRICE AND MEASUREMENT OF GRADING

Basis.

46. Grading shall be estimated and paid for by the cubic yard at the prices specified for the respective materials. Measurements shall be made in excavation only, except as hereinafter mentioned.

Work Included in Price.

47. The contract price per cubic yard shall include the excavation of the material by any method whatsoever; the loading, transportation and deposit of the same in the manner prescribed by these specifications and in the places designated; the plowing or benching of the slopes, and all other expenses incident to the work of grading.

Haul.

48. Unless otherwise specified, it is distinctly understood that the contract price per cubic yard covers any haul found necessary. No allowance will be made for any so-termed overhaul.

(ALTERNATE OPTIONAL OVERHAUL CLAUSE)

(The following alternate optional overhaul clause is recommended to be substituted for clause No. 48 of the Specifications for the Formation of the Roadway in case it is desired to allow overhaul.)

Haul.

48*a*. No payment shall be made for hauling material when the length of haul does not exceed the limit of free haul, which shall be .... (........) ft.

The limits of free haul shall be determined by fixing on the profile two points—one on each side of the neutral grade point—one in excavation and the other in embankment, such that the distance between them shall equal the specified free-haul limit and such that the included quantities of excavation and embankment shall balance. All haul of material beyond the free-haul limit shall be estimated and paid for on the basis of the following method of computation, viz.:

All material within this limit of free haul shall be eliminated from further consideration.

The distance between the center of gravity of the remaining mass of excavation and the center of gravity of the resulting embankment, less the limit of free haul as above described, shall be the overhaul distance.

Overhaul shall be computed in units of 1 cu.yd. moved 100 ft., and compensation to be rendered therefor shall be computed on such units.

In case material is obtained from borrow pits along the embankment and runways constructed, the haul shall be determined by the distance the team necessarily travels. The overhaul shall be determined by multiplying the number of cubic yards so hauled by one-half of the round distance made by the team, less the free-haul distance. The runways shall be established by the engineer.

Embankment Measurement.

49. If it be impracticable to measure borrowed material in excavation, it may be measured in embankment, using the cross-section notes of the embankment, and making a just and reasonable allowance for change in bulk, so that the quantities shall equal the excavation quantities as nearly as possible.

Borrow Classification.

50. No classification or allowance shall be made for loose or solid rock in borrow pits unless specific written instructions are given to the contrary, it being the intent and meaning of these specifications that all borrowed material shall be classified and paid for as common excavation.

TUNNEL EXCAVATION

Line, Grade and Cross-section.

51. Tunnels shall be excavated to the alignment, gradient and sections shown upon the plans, or to such modifications thereof as may be directed.

Bottom of Rock Tunnels.

52. The material from rock tunnels shall be taken out .... (........) ins. below subgrade and refilled to subgrade with approved material.

Blasting.

53. Blasting shall be done with all possible care so as not to damage the roof and sides. All insecure pieces of rock beyond the standard cross-section shall be removed by the contractor.

Excess Excavation.

54. Excavation in excess of the authorized cross-section shall not be paid for.

Price to Include.

55. The price paid for tunnel excavation shall embrace the cost of removal of all materials between the outer faces of the portals. It

shall include the loosening, loading, transportation and placing of the materials in embankment or waste banks, as directed. It shall also include whatever materials and labor are required for temporary props, supports and scaffolding for the safe prosecution of the work, as well as all expense of keeping the tunnel ventilated and free from water, oil or gas.

Niches or Recesses.

56. Niches or recesses for the protection and convenience of the railway employees shall be provided at designated intervals.

Shafts.

57. The location, number and dimensions of all shafts shall be determined. The excavation price for them shall cover all materials contained within the specified cross-section between the surface of the ground and the connection of the shafts with the tunnel. The price shall also cover all material and labor for curbing and support of the sides of the shafts as may be required, the cost of keeping the shafts ventilated and free from water, oil or gas, as well as the cost of all pumping and hoisting machinery.

Wells or Sumps.

58. Wells or sumps within the tunnel necessary for its permanent drainage shall be made as directed and paid for at the same rate per cubic yard as for tunnel excavation.

Right of Way for Roads.

59. The contractor shall, without loss or liability to the company, construct all roads necessary for his use in the execution of this contract.

Haul.

60. The contract price per cubic yard for tunnel and shaft excavation respectively covers any haul found necessary in placing the material where designated, within the limits agreed upon. There shall be no allowance for so-termed overhaul.

Clauses Specially Applicable to Revision of Existing Line or Widening for Additional Track

Safety of and Delay of Trains.

61. The contractor shall arrange his work so that there will be no interference or delay in any manner with the train service of the company. He shall be responsible for any damage to the company's property caused by his acts or those of his employees. Whenever the

work is liable to affect the movement or safety of trains, the method of doing such work shall first be submitted for approval, without which it shall not be commenced or prosecuted. If continuous detention occurs to the train service, the company reserves the right to complete the work at the expense of the contractor after giving him written notice.

Precautions for Safety of Trains and Tracks.

62. Heavy blasting shall not be permitted close to the main tracks, nor shall the contractor be permitted to transport material along or between the company's tracks, except when properly authorized. Whenever the work authorized affects the safety of the trains or tracks, the company shall take such precautions as it may deem advisable to insure safety. The cost thereof shall be charged to the contractor and deducted from his estimate.

When and How Company's Tracks May Be Moved.

63. The contractor shall not move the company's tracks or in any way interfere with them under any circumstances. Whenever it becomes necessary that the main line or side tracks be moved, it shall be done by the company, and the actual cost thereof charged to the contractor and deducted from his estimate.

Location of Additional Tracks.

64. The location of additional tracks shall be on the .... side of the existing line. But whenever it is expedient to change any portion to the opposite side, the altered alignment shall be shown upon the maps or diagrams furnished by the company, and the contractor shall conform to the same without extra charge.

Plowing Slopes.

65. Whenever the existing embankment of .... (........) ft. in height or over is raised or widened, the slope of the existing embankment shall be deeply plowed to bind the new material thoroughly to it.

Crossings.

66. Whenever it is necessary for any material of any description to be transported across the existing track or tracks, the location of the crossings must be approved. The material and labor for placing and maintaining the same shall be furnished by the company. The actual cost shall be charged to the company and deducted from his estimate.

Watchmen, Operators and Flagmen.

67. Day and night watchmen shall be furnished by the company at the places it may consider necessary for the safety of the company's

trains and works. The cost shall be charged to the contractor and deducted from his estimate. It is distinctly understood, however, that the providing of such watchmen shall not relieve the contractor from the liability and payment for damages caused by his operations.

Safety Signals.

68. The cost of installment, maintenance and operation of all signals necessary to ensure the safety of trains, consequent upon the contractor's work, shall be borne by the contractor, and all instructions regarding their observance shall be strictly obeyed by him.

GENERAL CONDITIONS

Temporary Fences.

69. Previous to, or during the work of grading, the contractor, if directed, shall erect and maintain temporary fences in order to prevent trespass upon the railway or damage to adjoining property.

Crossings, Damage to Property.

70. The contractor shall, at his own expense, make and keep in good condition commodious passing places for public and private roads traversed by the railway; and he shall be held responsible for damages of whatsoever nature to persons or to neighboring property caused by workmen in his employ leaving gates or fences open, blasting rock, building fires or in other ways. If necessary, the payment of the estimate may be withheld until such damages are satisfactorily adjusted. The intention of the contract is that the company shall not be held responsible for any claim or losses incurred during the construction of the line due to the operation or negligence of the contractor or his employees.

Changes of Alignment or Gradients.

71. The alignment, gradients, and cross-sections of the roadbed, as well as ditches and other incidental work, may be altered in whole or in part, as deemed necessary, either before or after the commencement of the work. But any change or alteration may not affect the unit prices specified in the contract; nor shall any such changes or alterations constitute claims for damages, nor shall any claim be made or allowed on account of such changes or alterations.

Snow and Ice.

72. Before beginning and during the progress of the work, the contractor shall remove all snow and ice between the slope stakes at his own expense.

Bench Marks and Stakes.

73. The contractor shall carefully preserve all bench marks and stakes. In case of neglect to do so, he shall be charged with the resulting expense.

Roads.

74. Whenever required, the contractor shall open up a safe road for passage on horseback and foot along the whole or any portion of the work under contract.

Temporary Roads, Trestles, etc.

75. No allowance or compensation whatsoever shall be due or paid to the contractor for any temporary roads, bridges or trestles that he may make to facilitate the work.

Final Clearing Up.

76. Before the work is finally accepted the contractor shall at his own expense clear away from the company's property, as well as from public and private roads and channels of streams and ditches, all rubbish and surplus blasted or excavated material.

Extra Work.

77. The cost of any extra work shall not be considered or allowed, unless such extra work shall be done by direction in writing. Such written directions shall in every case contain the rates and methods of payment for such extra work.

Contractor's Risk.

The contractor shall take all risks from casualties of every nature, and shall not be entitled to any compensation for detention from such causes. The contractor assumes risk of personal liability and damage to stock, tools and machinery used on the work while on the property of the railway company, and the contractor agrees to make no claim therefor which may be caused by the operation of the railway.

Company Defined.

79. Wherever the word "Company" is used in these specifications, it designates the .... Company.

Contractor Defined.

80. The word "Contractor" is used herein to designate the person or persons undertaking the work referred to in these specifications and drawings.

Work in Charge of.

81. In the foregoing specifications it is understood and agreed that the Chief Engineer of the .... Company is in charge of the work, and that he may appoint such assistants as he may elect. Whenever the specifications refer to the judgment, direction, decision, approval, etc., of any employee of the .... Company, they designate and mean the Chief Engineer or one of his assistants. The decision of the Chief Engineer shall be final as to the intent and meaning of these specifications.

Specifications Part of Contract.

82. The specifications and general conditions referred to are distinctly understood as being embodied with the contract, the whole forming the entire agreement between the company and the contractor.

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